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Margot J. Wojciechowski

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FOREWORD

This volume contains the proceedings of the 13th CRS Policy Discussion Seminar. The CRS seminar series brings together individuals from industry, government, labour, universities, and other organizations to share their knowledge and views on selected policy issues. The subject of productivity was selected because of its vital importance to the long-term viability of the Canadian mineral industry, in the face of growing competition from low-cost producers throughout the world.

The seminar was held at the Donald Gordon Centre for Continuing Education in Kingston, Ontario on March 7-9, 1984. The program was arranged by Peter Richardson of Queen's School of Business. The proceedings volume was edited by Margot Wojciechowski and produced by Donna Beaubien.

The Centre is grateful for the contributions of the speakers and the participants, both during the seminar and in the preparation of the proceedings. Views expressed are those of individual participants, and do not necessarily represent the views of the Centre or its sponsors.

Margot J. Wojciechowski
Centre for Resource Studies

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MEASURING MINING PRODUCTIVITY[1]

Peter R. Richardson

Productivity measures are used by different groups of people with a variety of purposes in mind. Economists attempt to measure productivity to establish how efficiently resources are used in an economy, and examine competition between industries. Corporate executives may wish to establish how their firm utilizes its inputs over time, and as compared to other firms. Within firms, department managers want to know the productivity of their employees and equipment for performance evaluation and payment purposes.

To meet these divergent needs, a variety of productivity measures has been developed, with differing levels of aggregation. Some apply to all industries, while others are industry and even operation specific. There are measures which consider only one factor input (such as labour), while others attempt to measure all factor inputs. The results are expressed in many different forms: e.g. ratios, indexes, and rates of change. This complexity has caused considerable confusion about what productivity is, and how it should be measured.

In mining, the situation is more complex than for most manufacturing industries because of many intervening factors which arise due to the unique characteristics of each orebody. Location, size, ore grade and complexity, and mining method are some of the factors affecting the apparent productivity of a mine.

The purpose of this paper is to clarify the situation by describing briefly the different approaches to measuring productivity which are relevant to the mining industry, and classifying them according to their function and their level of aggregation.

Productivity in the Canadian Mining Industry

The productivity of Canadian mines compared to those in other countries is increasingly important for this country's international competitiveness and balance of trade. Mineral products are largely undifferentiated in their crude or semi-fabricated forms, and so competition is largely on the basis of price. Since a large proportion of Canada's mineral products are exported, and must remain competitive in world markets, they must be produced at a low cost. Productivity is the single most important determinant of competitiveness that firms in the mining industry can control:

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[1] Background paper prepared for the 13th CRS Policy Discussion Seminar on Mining Productivity.

Hence, the critical questions in this respect are:

- How productive are Canada's mines compared to those in other countries?
- How does productivity vary by industry sector?
- What are the trends in productivity change, and what changes are foreseen in the future?

To answer these questions, we need productivity measures that are reliable and can be understood by those studying the industry's problems. Several economic studies have attempted to produce such measures, but either the methodology has been criticized, or, for a variety of reasons, the studies have not been understood and used by decision-makers as a basis for company and industry policies. Instead, the industry continues to rely on traditional partial productivity measures, which present an incomplete picture and which may be misleading when used as the basis for policy decisions.

Types of Productivity Measure

Productivity is easy to define, but hard to measure. As a measure of the efficiency with which inputs into some system are transformed into outputs, productivity is comprehensively defined by the equation:

$$\text{PRODUCTIVITY} = \frac{\text{OUTPUT}}{\text{INPUT}}$$

where INPUT = f(L, C, R, Q)

and L = labour;
C = capital;
R = natural resources, raw materials;
Q = other factors, e.g. technology, management, etc.

In practice, however, there are many problems associated with measuring productivity. There is the difficulty in measuring output and the various inputs in common units. Physical units of input are not usually directly comparable, and so a common measure must be identified. If monetary units are selected, valuation is a difficult and complex issue. Also, it is difficult to determine quantities and values for intangible outputs, such as service or quality, and inputs, such as technology and management.

These measurement problems are compounded by a variety of external factors which may distort the results obtained. For example, changes in ore grade or variations in capacity utilization may significantly affect the apparent productivity of mining operations.

A variety of measures has been developed in an attempt to overcome these problems. These can be classified along two dimensions relevant to the problem at hand:

i by level of aggregation, e.g. industry, firm, and department;
ii by type of measure, e.g. complex, total or partial.

The resulting matrix is shown in figure 1. Each type of measure involves different assumptions, provides different information, and can be used for different purposes. For instance, input-output measures by industry sector provide economists with useful information about the relative efficiency of resource allocations in different sectors, and can be used for industry and international comparisons. In contrast, partial measures (for example, of labour productivity at the department level) may give highly misleading information in this respect, but do provide useful information on which to base management decisions within the firm.

Industry Measures

Traditionally, productivity in the industrial sector has been measured in terms of output per man-hour worked, which is a partial measure of factor productivity. For statistical reporting by government agencies in the United States and Canada, this measure is derived by dividing sectoral or industry gross domestic product by the corresponding hours of all persons employed. Value added is also used as a measure of output on occasion.

Output per man-hour has the advantage of simplicity, but suffers from many shortcomings, along with other partial measures. For instance, they often fail to make ade-

Type of Measure	Industry Aggregation		
	Industry or Sector	Firm	Department
Complex	Input-output (comparative)	Managerial control ratio (comparative)	Managerial control ratio (disaggregated)
Total	Total factor index (sector or industry specific	Total factor index (firm-specific) (trends)	
Partial		Partial factor measures (comparative and trends)	Partial factor measures (comparative and trends

Figure 1. Productivity Measures: Aggregation and Type

quate adjustments for changes over time. As a consequence, price increases or other changes may result in apparent productivity gains. In addition, this measure does not take into account substitution of capital for labour or the impact of technology change. The limitations of partial factor analysis have been comprehensively described in a recent article.[2]

In an attempt to overcome the limitations of partial analysis, total factor productivity indices have been developed. These indices have been refined and improved over the last twenty years, and form the basis for recent studies of mining industry productivity in Canada.

At sectoral and industry levels of aggregation, capital and labour are the two most widely investigated factors. Total factor productivity (A) at a point in time is obtained by applying appropriate weights (W1 and W2) to the capital (K), and labout (L) inputs, as shown below:

$$A = \frac{V}{(W1*K + W2*L)}$$

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[2] Albert Ross, 'Improving Concepts and Techniques of Productivity Measurement', Monthly Labour Review, vol. 102, no. 9, September 1979, pp. 23-27.

The impact of technological and managerial changes can be inferred from this approach by examining changes through time. The geometric index of productivity growth (G) can be obtained as follows:

$$G = \frac{dV}{V} - (W1 * \frac{dL}{L} + W2 * \frac{dK}{K})$$

This index is also referred to by many economists as the index of technical change.

These indices are useful only over relatively long periods of analysis, since short-term factors such as capacity utilization or strikes can cause periodic fluctuations. Indices do not provide a valid basis for inter-industry comparisons, since they have unique base points, and may ignore many industry-specific factors. Moreover, they do not explain the causes of productivity change.

Earlier studies of total factor productivity in the Canadian mining industry suffered from many of these shortcomings.[3] In addition, the data for these studies were derived from government statistics which were not aggregated in the most appropriate form. Factor weightings for these studies used data from input-output studies of the Canadian economy which were out of date, and inaccurate, since these coefficients change over time.

A more recent study by Stollery[4] applies recent advances in this methodology, although it still suffers from data problems. This study presents a set of hypotheses for the causes of an apparent decline in mining productivity in Canada, and then attempts to explain them by examining trends in labour and total factor productivity. Stollery sets up a production function (Q) which is a function of labour (L), capital (K), and energy (E) inputs, with time (t) as a proxy for technique, as shown below.

$$Q = f(l, k, E, t)$$

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3. F.R. Anton, 'Productivity in the Mineral Industry', Preliminary Report for the Department of Energy, Mines and Resources, Ottawa, 1973; and John Dawson, *Productivity Change in Canadian Mining Industries*, Economic Council Study No. 30, Ottawa, 1971.
4. K.R. Stollery, *Productivity Trends and their Causes in the Canadian Mining Industry, 1957-1979*, Economic Council of Canada, Discussion Paper No. 248, December 1983. See also Stollery's paper in this proceedings volume.

However, to measure productivity, the study uses a general cost function for the industry, and for several specific mineral types, of the form:

$$C = F(Q, Pl, Pk, Pe, g, t)$$

where Pl, Pe and Pk are factor prices and g is mineral grade. Using this approach, Stollery attributes changes in total factor productivity to factors such as scale economies, technical change, and grade changes, thus providing the model with some explanatory power. However, the usefulness of this approach is limited, due to simplifying assumptions made in deriving production and cost functions, and also to the quality of data sources.

A more complex method that has been developed for examining productivity within economies and industry sectors is the input-output model. In this approach, the outputs of each industry or sector are viewed as a commodity input to other industries or sectors. Since being developed by Leontief,[5] the model has undergone substantial refinement.

The input-output model assumes a linear production function for each of n industries, relating output (Xi) to the output of each industry consumed by others (Oij) through a coefficient of production (Aij):

$$Oij = \frac{Aij}{Bi * Cj} * Xi$$

Bi is called the productivity coefficient of industry i, and Ci is called the productivity coefficient of commodity i.

Then, the production and consumption of the total economy are represented by:

$$\sum_{i=1}^{n} (1-dij) * \frac{Aij}{Bi * Cj} * Xi-Xj = 0$$

If the productivity coefficient (Bi) of industry i increases, then to produce each unit of Xi, less resources are needed from other industries. However, if the productivity coefficient of commodity i (Ci) increases while Bi remains constant, then each unit of output from industry i has become more efficient, and so other industries can do with less of commodity i.

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[5] Wassily W. Leontief, Input-Output Economics, (New York: Oxford University Press, 1951).

Despite some restrictive assumptions, such as the linear production function, the power of the input-output model is such that it has been used for a variety of purposes. Attempts have been made to use the technique for examining productivity in the Canadian mining industry. Studies of the impact of technological change on productivity have also been made with the model.

The Firm Level

While profit and return on investment are the most widely used measure of corporate performance, they are not measures of firm productivity or efficiency, as many economists have noted. Rather, profit is a residual, and if it measures anything, it is the effectiveness of the firm in meeting its goals and objectives. Consequently, there has been a continuing search for relevant productivity measures for individual firms.

The most commonly used measures of productivity are partial measures, which suffer from the same drawbacks for firms as they do at industry or sector levels of aggregation. Nevertheless, tons per man-hour, return on investment, revenues per dollar of invested capital, and tons of annual capacity per investment dollar remain the most common yardsticks of labour and capital productivity in the mining industry. Similar measures are used in all other industries. For instance, revenue per square foot (or metre?) of floor-space is known as the 'iron law' of retailing.

Several total factor productivity measures have been developed for use at the firm level, although they are not widely used. The one that is most often quoted is that developed by Craig and Harris.[6] Their index considers total factor inputs consumed in producing specified outputs. A base year is selected which characterizes the normal corporate pattern for input costs and selling prices. These are then converted to constant dollar terms to eliminate the effect of inflation. The index they developed has been used to measure changes in productivity within firms, but is not useful for comparison purposes. Similar measures have been proposed by Hayes (1982),[7] and Mammone (1980).[8]

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[6] Charles E. Craig and R. Clark Harris, 'Total Productivity Measurement at the Firm Level', Sloan Management Review, Spring, 1973.

A more complex system of managerial control ratios to measure productivity has been proposed and applied in practical situations by Gold,[9] who pointed out that firms do not exist to maximize a set of physical outputs relative to a given set of inputs. Rather, the firm is viewed as a linkage system, tying physical productivity measures to managerial and financial criteria such as sales growth and return on investment.

Gold's basic network of productivity relationships among input factors is shown in figure 2. Of the six components identified, three cover input requirements per unit of output:

- output/man-hour;
- output/materials volume;
- capacity/fixed investment.

Three relate to the proportions in which these are combined:

- man-hours/(fixed investment x capacity utilization) (1);
- materials volume/man-hours (2);
- materials volume/(fixed investment x capacity utilization) (3).

Gold circumvents the capacity utilization problem by relating inputs to actively utilized net fixed investment.

To link this network of physical productivity relationships to financial performance, Gold superimposes a cost and investment structure onto the basic network (see figure 3). This allows the cost and profit effects of changes in input requirements and factor proportions to be examined, not only in a historic sense, but also prescriptively, as an aid to decision making. The approach has not, so far, been applied to mineral industry firms.

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[7] Robert H. Hayes, 'A Note on Productivity Accounting', Harvard Business School, Boston, 1981.

[8] James L. Mammone, 'A Practical Approach to Productivity Measurement', Management Accounting, July 1980, pp. 40-44.

[9] Bela Gold, Productivity, Technology and Capital, (Lexington, Mass: Lexington Books, 1979).

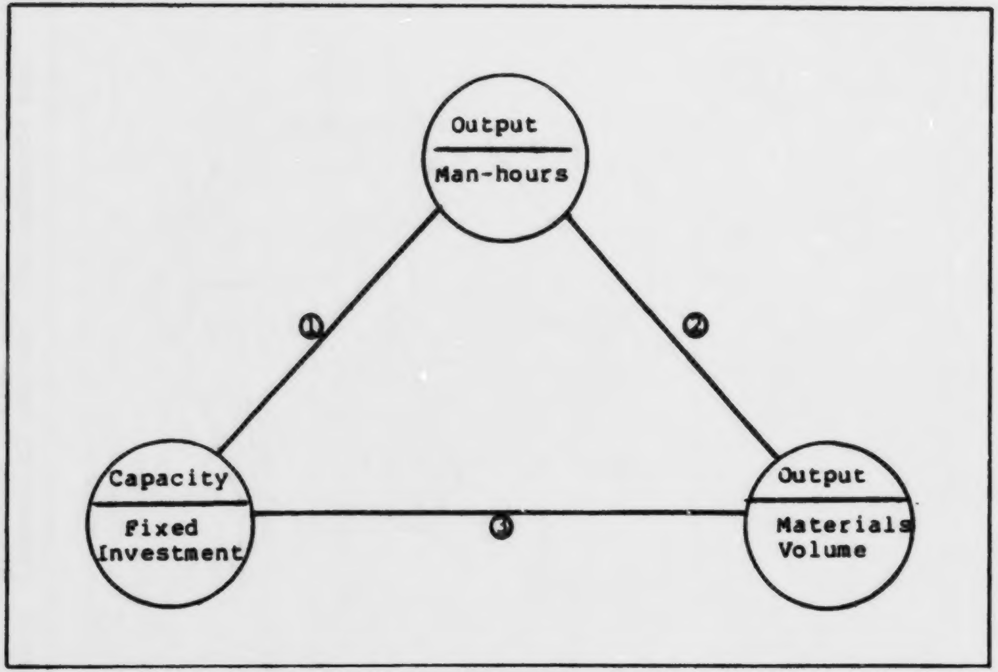
Output
Man-hours
①
②
Capacity
Fixed Investment
③
Output
Materials Volume

Figure 2. Network of Productivity Relationships

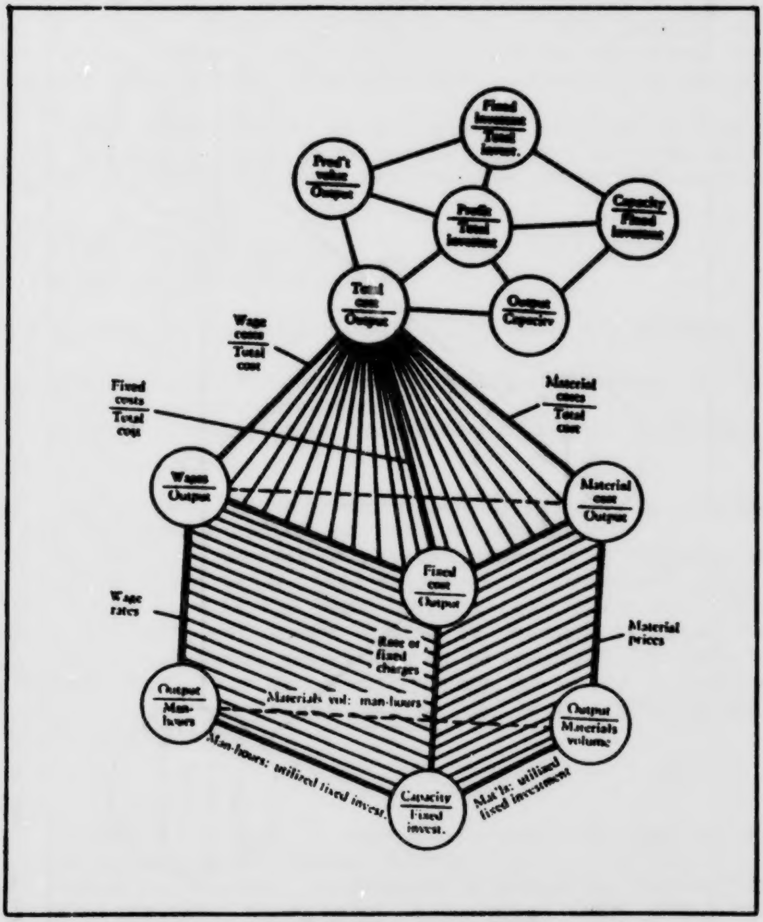
Fixed investment / Total invest.
Prod't value / Output
Profit / Total investment
Capacity / Fixed investment
Total cost / Output
Output / Capacity
Wage costs / Total cost
Fixed costs / Total cost
Material costs / Total cost
Wages / Output
Material cost / Output
Fixed cost / Output
Wage rates
Rate of fixed charges
Material prices
Output / Man-hours
Materials vol: man-hours
Output / Materials volume
Man-hours: utilized fixed invest.
Capacity / Fixed invest.
Mat'ls: utilized fixed investment

Figure 3. Productivity Network, Cost Structure and Managerial Control Ratios

Departmental and Sub-unit Analysis

Productivity measures at levels of aggregation lower than the firm are frequently required for payment purposes, especially where bonuses are used. A variety of measures, many of them operation specific, have been developed to measure productivity for these purposes.

Measuring productivity for organizational sub-units is easier than for firms or industries, because physical inputs and outputs can frequently be employed as direct measures. Also, there are fewer external factors which affect measured performance. However, if the output of the sub-unit is a service, or if quality is an important determinant of productivity, the measurement problem again becomes limiting. An example of this situation arises in mining, where underground miners are commonly paid a production bonus, but underground mechanics are not, largely because their output is difficult to measure.

Many partial measures have been developed for determining the productivity of organizational sub-units. Most commonly, these are expressed in terms of output per man-hour (or man-shift) worked. Other partial measures of productivity include feet of advance per shift, equipment availability and utilization, and mineral recoveries.

These partial measures are often used as the basis of inter-firm productivity comparisons, since indexes and complex measures such as those proposed by Gold are difficult to use for this purpose. Unfortunately, when applied in this way these measures can be misleading because of intervening variables which make direct comparisons fallacious. For example, comparisons of tons of ore per man-shift at different mining operations may fail to capture the impact of different mining methods, ground conditions, or equipment used.

Total factor productivity indexes applicable to the firm can also be used at the plant or department level. Such measures are common where gain sharing or other forms of productivity improvement programs are employed. The Scanlon plan, for example, establishes an index for labour productivity which takes into account major technical and capital changes.[10] However, valid measurements of productivity are frequently the cause of considerable conflict in these schemes.

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[10] See for example Brian E. Moore and Timothy L. Ross, The Scanlon Way to Improved Productivity, (New York: Wiley-Interscience, 1978).

Firms tend to use a variety of partial factor measures to describe plant or departmental productivity. While these are not as precisely structured as Gold's complex productivity measure described earlier, they can form a comprehensive picture of labour and capital productivity for management.

In mining, because of the relatively standard form of commodity products, cost per unit of final output (tons of concentrate or metal, not tons of ore) is frequently taken by managers as an overall indicator of productivity, with lower costs per unit indicating higher productivity and competitiveness. Most international studies of mining industry performance use this measure to rank producers.

Since this measure taken alone can be quite misleading (due to variations in grade, mining method, equipment, etc.) a variety of other measures is needed to complete an overall picture.

Concluding Comment

The purpose of this paper has been to reduce the confusion surrounding the measurement of productivity, and the purpose for which these measures are intended. The paper has shown that there is no best way to measure productivity, and all methods have their short-comings. When viewed in the context of varying levels of aggregation, however, each method of measurement can be seen to be more or less appropriate to particular types of investigation and decision making.

Industry and sectoral comparisons of productivity (i.e. the efficiency with which resources are utilized in the economy) are needed to guide fiscal and industrial policy decisions. Input-output techniques are widely used for these purposes and have proved extremely useful. Total factor productivity indexes have been used widely to establish and explain observed trends in productivity change within industries. Partial measures, however, are of limited value at this level of aggregation, except in the context of more comprehensive measures, even though they continue to be widely used for comparison purposes.

Productivity analysis at the firm level is still embryonic, in so far as complex or total factor measures are concerned. Inter-firm comparisons and performances trends are still calculated on the basis of partial measures, of which the most important is return on investment, although, as noted, this is a poor indicator of true productivity. One of the main reasons for this state of affairs is, as Gold points out, that firms are not in business to maximize physical outputs relative to inputs. Rather, they are profit-oriented, and while labour and capital productivity are important, their efficient use is not necessarily central to profitability and business success.

Productivity measurement is well developed at the organization sub-unit level. Measurement of plant, departmental, and operating unit productivity is common throughout industry, with a wide range of partial and total factor productivity measures being used as an aid to decision making. However, these measures can be extremely misleading if they are used as the basis for comparisons across different industries and countries, because of factors not considered in the analysis.

Since measures of productivity are important guides to a variety of economic and industrial decisions, it is important to ensure that the methodology employed is appropriate to the nature of the decisions at hand. In Canada, decisions taken at all levels of government and industry affect mining productivity and how it changes. Failure to base these decisions on appropriate and relevant measures and data could lead to considerable misallocation of resources, which, if continued for an extended period, might contribute to the decline of the industry. It is essential that executives in both industry and government understand productivity measurement, in order to ensure that the best possible decisions are made.

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DIGEST OF SEMINAR DISCUSSIONS

Margot J. Wojciechowski

Long-Term Prospects for the Canadian Mineral Industry

Real prices for many minerals have shown virtually no increase for years. In the case of nickel, price levels for 1983 were no better than 1977, while real copper prices were at their lowest level since the late 1940s. Even in current dollar figures, and ignoring short-term fluctuations, price trends in recent years have been steady or in some cases declining. Costs on the other hand have climbed steadily beginning in the latter part of the 1960s, with increases in wages, higher energy costs, higher costs for capital goods, higher interest rates, higher transportation costs, increased taxation, and increased requirements for health, safety, and environmental protection.

Despite these trends, as some participants pointed out, the Canadian mineral industry managed to stay financially healthy and competitive until the mid-1970s, largely through improvements in technology. New understanding of geological environments and new exploration techniques kept the costs of exploration at acceptable levels. New techniques and equipment for mining and mineral transportation permitted Canadian producers to put their products on world markets at competitive prices, while continuing to provide a return on investment. It was felt that productivity performance in mining was generally better than in other sectors through this period.

Late in the 1970s, cost/price curves crossed and began to diverge. This situation has been aggravated, seminar participants agreed, by the very slow growth in world markets for minerals in recent years, and the rapid erosion of Canada's share of those markets due to competition from new producers. As a result, a significant part of Canada's mineral-producing capacity, installed in a short-lived period of concern over future shortages, stands idle. Partly as a consequence of this idle capacity, there has been a growing impression that the productivity performance of the mining industry is trailing that for the Canadian economy as a whole. As a consequence, some economists and policy makers have developed a growing but, many believe, unwarranted, conviction that the trends are irreversible and long-term, and that the industry is in decline - in effect, a 'sunset' industry.

The seminar participants concluded that this view is based on faulty analysis. Moreover, it leads to a serious misconception regarding the industry's future, one that is both misguided and dangerous. It is misguided in that it ignores two important considerations:

- first, only some commodities are in difficulty - many, such as gold, potash and uranium, are still doing well, and others have excellent potential;
- second, there has been a major reversal in the last two to three years among a significant number of producers, a reversal that has cut their costs dramatically, improved productivity, and put them on the road to economic recovery.

The misconception was also described as dangerous, in that it could affect:

- the availability of finance for new projects and even ongoing operations;
- the taxation regime and associated incentives for the industry;
- government assistance programs, available for short-term emergencies but not for industries in long-term decline;
- purchasers' view of Canada as a reliable long-term supplier of minerals.

The result could be the unnecessary loss of companies and economic activities that hold considerable potential to generate long-term employment and wealth for Canada.

Participants concluded therefore that two major efforts are required with respect to productivity. The first and most obvious is to continue to expand the ongoing process of productivity improvement in Canadian mining. (A corollary of this is that high-cost noncompetitive Canadian mining operations would be a burden on the economy, if government should try to keep them open). The second effort should be directed at providing both industry and government policy makers with accurate and up-to-date information on real productivity trends in the Canadian mineral industry.

Role of Productivity in Mining's Long Term Prospects

For the mining industry, profitability is basically a function of the following factors:

- unit volume of inputs x unit input costs;
- volume of product sold x unit price.

Interest rates, wage levels and energy costs are largely beyond the control of mining companies, as is the unit price received for minerals. Therefore, only by reducing the amount of capital and/or labour employed per unit of output can rising costs be held in line with steady prices. This is the role of productivity improvement.

Improvements in exploration technology will reduce the cost of finding economic deposits. They can lead to high-grade discoveries, reduce the time required for a discovery, and be directed at more accurate and rapid measurement of such factors as deposit configuration, multi-metal characteristics, etc. Improvements in mining methods, as described for example in the presentations by Eric Kossatz, Walter Curlook, and Bill James, have contributed to drastic cost reductions and increased productivity.

Marketing Considerations

In addition to looking at productivity questions, participants spent some time considering marketing questions: i.e. the problem of turning volume of minerals produced into volume of minerals sold. A mineral with a conspicuous marketing problem is nickel. Nickel has seen a real fall in demand, and Canadian producers have little or no prospect of recovering their old peak levels of market share. Among the reasons given for this pessimistic outlook were the following:

- energy megaprojects caused a surge of demand for a while, but no new energy megaprojects are likely;
- the USA, the major market for Canadian nickel, is losing its world market share for manufactured goods;
- Third-World countries such as China and Indonesia that are on the verge of a rapid rise in consumption also have large nickel resources.

For copper, the major marketing problem for Canadian producers is the challenge of meeting world prices, which are dismally low because of excess supply. As a result, only the very low-cost producers such as Codelco in Chile are able to realize a profit. Participants noted that Codelco has not relied solely on its high copper grades and on government protection to maintain its competitive position; good management, marketing, and productivity improvements in mining, smelting, and transportation have also played key roles.

Both Brian Felske and Ken Whitham stressed in their papers the necessity for research in new product development and applications, both to fight off encroaching substitution in order to maintain existing markets, and to open up new markets. The example of Alcan was cited by several participants; through research in processing and product development, Alcan has in the recent past kept its costs competitive and opened up significant new markets for its products.

Areas Identified as Ripe for Productivity Improvement

Participants felt that, for a number of minerals, a wide range of activities in the mineral production cycle are ripe for technological breakthroughs that will lead to reduced costs.

Management

First and foremost, improved skills and attitudes of management were identified as the single most important requirement for productivity improvement. Industry participants acknowledged that management had become complacent during years of high demand and high prices, and had neglected productivity improvement aspects of their business. However, there was strong support for the contention that the situation is in the process of correction. It was pointed out that virtually every major mining company in Canada has undergone extensive management reevaluation and reorganization in the last two years. Falconbridge for example has gone through a very difficult period of management and operations restructuring in which staff cuts, including at head office, have in some places been as high as 50 percent, with no loss of production. Costs for nickel production were cut by about $1.10/lb, an improvement of about 40 percent in 1983. A further 10-percent improvement is expected in 1984. At the same time, participants stressed that there is still a pressing need for increased awareness among mining companies and their executives of the necessity for productivity improvement in the industry.

Ore Grades

The popular conception that ore grades are declining was attacked by a number of participants as a serious misconception. Improved exploration techniques and approaches have led to significant new high grade discoveries close to existing infrastructure and in areas that had already been explored extensively. Among the examples supporting this view are Kidd Creek and Hemlo. Some participants felt there is no reason to consider these discoveries as anomalies, and that such finds will continue to be made. There was general agreement, however, on the need for more data and careful analysis of exploration productivity, in order to arrive at an accurate understanding of ore-grade trends.

Mining and Milling Losses

As Brian Mackenzie's figures showed, losses in mining and milling are fairly high for nonferrous base metals, and therefore these areas offer substantial potential for productivity improvement. Largely a function of ore grade and geochemical characteristics, such losses can also be reduced over time by exploration advances that lead to discovery of high grade deposits which are easily concentrated, so that lower grade and more refractory deposits can be ignored until technology catches up with them. There is also room for improvement in the techniques of mining and milling that will leave less of the ore grade material in the mine, or metal in the waste and in the tailings. Improvement of recovery rates for mining and milling is one of the easiest ways of increasing potential reserves on a property, and may be more cost effective in some instances than on-property exploration.

Mining Methods

The presentation of Eric Kossatz and Walter Curlook described significant advances in mining productivity in Inco's research mine, Copper Cliff North, advances which are already being put into practice in other mines. Reductions in underground costs as high as 80 percent have been achieved by adoption of vertical retreat mining methods, in conjunction with other innovations. By any measure of productivity, be it tons per man shift, operating costs per ton, or even operating and capital cost per ton, great improvements have been made. The techniques have also been applied to Inco's Garson mine, which has realized a 250-percent improvement in productivity and is expected to reach 300 percent. Similar success stories were recounted by other producers. Selbaie, for example, has also adopted a similar vertical retreat method, and found it very economical.

Inco believes that the lessons learned in its research mine will revolutionize mine design, shorten the development period, reduce equipment needs, and cut capital costs by over 60 percent. Further improvements are expected from Hrdk Mining Research Corporation, a joint research venture in hardrock mining methods supported by Inco, Noranda, Falconbridge and Kidd Creek.

Transportation of Ore

Transportation of ore was identified by one participant as the biggest single area for productivity improvement in mining. Mining is basically moving ore, and although equipment presently in use, such as the scoop tram, represents an improvement over older methods, the optimum solution is still to be found. It was suggested that continuous methods of materials handling such as belts and slurries offer promising areas for further development. Underground crushing and preconcentration also merit further study.

Labour

Mining company representatives agreed that labour skills and attitudes can be significant sources of productivity problems, and that management must bear the major responsibility for their correction. It was noted, however, that labour tends to bear the economic brunt in bad times, and that it would be appropriate for management's appreciation of labour to extend into the good times with equal enthusiasm.

Gain sharing as a means of improving the productivity of labour was described in Paul LePage's presentation. Participants agreed that, to be effective, a gain sharing program should be based on productivity improvement and prescribed work goals, not on corporate or even mine profits. It is a program that has worked successfully, but it can be very difficult to operate. For example, the base must be adjusted regularly, along with the rewards associated with various levels of productivity improvement; otherwise, the program will die away as the limits of improvement are approached in some areas. Another problem is that productivity improvements may lead to lower manpower requirements; unless these are met by attrition alone, employee enthusiasm for the program may go out the window along with the resulting lay-offs. Furthermore, unions should be open and willing to cooperate in establishing such programs successfully.

Marketing

Although this downstream activity may seem somewhat removed from productivity as measured by tons per manshift, it is clearly part of the overall productivity picture of the industry. Improved sales improve the return on capital and other inputs. Under present conditions of low capacity utilization, they also permit increased utilization and therefore more productive use of capital.

Extensive structural changes, different for virtually each commodity, have occurred in the patterns of production and consumption of mineral products. The emergence of new producers, changes in consumption habits, substitution, restrictions to free trade through international agreements, and other trends must be understood in terms of their long-term implications for prices and markets for Canadian minerals.

When the question of cartels was raised, the response was that they are of very little usefulness to Canadian producers. For nickel, for example, it was felt that a better answer was to learn to live with $2.50/lb and close down the facilities that cannot produce at that price.

Product Development

Brian Felske described new product development as the only direction in which Canada has a real technological advantage, and the only direction for significant economic gains for the industry. While other participants tended to have higher hopes for the ongoing cost-cutting and productivity efforts, there was general agreement that new product development is an important and, outside of the aluminum industry, a neglected area.

It was noted that Inco, formerly very active in research into new uses for nickel, has had to give up much of its research effort as its market share and profits fell. The company would like to see a renewal of research in this area, but wants the costs shared by other producers. Joint ventures, Canadian or international, paralleling such been applied to Inco's Garson mine, which has realized a 250-percent improvement in productivity and is expected to reach 300 percent. Similar success stories were recounted by other producers. Selbaie, for example, has also adopted a similar vertical retreat method, and found it very economical.

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Government Involvement in Productivity Issues

The presentations by George Miller and Ken Whitham described a number of government programs designed to assist the mining industry by reducing its costs. Some, such as CANMET research programs and the activities of the geological survey can be aimed directly at improving productivity in mining and exploration, while others, such as tax incentives and job assistance programs, are less direct.

The federal income tax act excludes from the definition of research and development any activity in which there is any actual mine development or production of minerals involved. This limits fiscal incentives for R and D in mining, since much of the industry's research is of a demonstration nature in producing mines; there are efforts under way to find ways around this dilemma. However, participants commented favourably on existing taxation incentives for research and development, as well as for exploration, particularly the introduction of flow-through measures. On the other hand, it was suggested that the present taxation system discriminates against rapidly-growing companies, which may be the most likely to introduce new technology and productivity improvements.

CANMET assistance can take the form of shared-risk demonstration projects in joint ventures with industry. The base of funding for such activities is small, and alternative funding mechanisms are under consideration.

It was suggested that greater industry involvement in designing the expenditure program under federal-provincial mineral development agreements might increase the value of such programs to the mineral sector as a whole, by coordinating the total effort. At present, these mineral programs involve initial consultation between the federal and provincial planning agencies, and then between the federal and provincial mines departments, and some industry consultation. For example, CANMET has met with mining industry representatives in Manitoba, and plans to strengthen such consultations in Ontario and elsewhere. One of the major concerns expressed was that much of the work being done was of little value to industry. Industry representatives indicated that they would like to see more work done on technological and economic development aspects in these programs.

One participant raised the question of government-provided services and their cost to the industry. He pointed out that many services such as electricity, transportation, port facilities etc. are provided by government agencies and Crown corporations. The costs of these services can be a significant proportion of the cost of production. For potash, for example, he suggested that as much as 50 percent of the cost of getting it to the border shipping points can be attributed to transportation. He pointed out that, unless government agencies and Crown corporations share industry's concern for productivity improvement and cut their own costs, the private sector's efforts may be swallowed up.

The issue of government-imposed expenditures was also raised, particularly regarding SO_2 emission controls. One company, for example, which has brought its emission level down to 14 percent now faces a requirement to drop to 7 percent. This is a much more difficult task. The cost is estimated at $140 million, which is an impossible burden at present nickel prices, as it would add about 60 cents per pound to a $2-$3 per pound commodity, under current financing conditions.

Productivity Measurement

The preceding sections have described the discussions relating to the belief that the mineral industry is improving in productivity performance, and that there is much scope for further improvement. This section looks at a more fundamental issue, in which there was much less agreement among participants: the question of productivity measurement. Discussions covered such areas as:

- the availability of data for useful and up-to-date productivity studies;
- the level of aggregation and disaggregation that is useful - this includes disaggregation by commodity, by input factors (capital, labour etc.) by individual mines (to account for multi-metal mines etc.) or by sectors (e.g. metallic, or base metals, or nonferrous etc.);
- the purpose of various measures of productivity;
- a number of measurement concepts, such as dollars vs tons, and economies of scale;
- the accuracy of actual productivity studies;
- the need for and the possibility of producing useful and accurate total factor productivity studies for the guidance of private and public sector policy makers;
- the use of Statistics Canada data on ore grades.

Aggregation of Productivity Data

Peter Richardson's background paper set out a matrix showing relationships between level of data aggregation, number of factors measured, and the purpose for which the information was to be used. In the course of the discussions it became apparent that this matrix greatly simplifies reality, where the relationships are much more complicated, with gaps, overlaps, and confusions in measurement and understanding. There is great difficulty in developing useful discussions between, say, economists, managers, and engineers, each of whom have differing views and measures.

Mine by Mine

Some industry participants felt that the only useful measure of productivity is tons of ore per manshift, used as means of comparing performance over time in a mine, between mines, or as compared to some theoretical goal (i.e. a measure of the 'excellence gap' at a point in time). While tons per manshift was recognized as an essential tool for management, its wider application was felt to be invalid, for a number of reasons:

i it does not allow for difference between mines, for example in grade, ore type and configuration, by-product metals, etc.;
ii it does not take returns on capital into account;
iii data in dollar terms are more useful for aggregation into larger studies.

Comparisons or aggregations of mine data should therefore be in terms such as Net Smelter Returns, which should consider all input factors and account for all metals which have been paid for.

Commodity

Some participants felt that commodities represent the greatest level of aggregation for the establishment of meaningful statistical trends for national or international studies. Felske's comparisons of Canadian and Third World copper producers, for example, were felt to be realistic and useful to both private and public sector planners. Any attempt to combine commodities, it was suggested, would be misleading.

On the other hand, it was pointed out that concentrating exclusively on single commodities would distort the outlook for some mines. Falconbridge, for example, made money on nickel in only 2 years since 1975, but managed to stay in the black for most of those years because of by-product metals. Many copper producers are in a similar situation. Ignoring by-product metals therefore can totally invalidate productivity findings. The same is true of ignoring the differences between open pit and underground operations.

Stollery's use of copper data aggregated at the national level to identify 'economies of scale' was a complete puzzle to many participants. To an economist, the term can involve a simple relationship between total volume of output and cost per unit. To a mine manager, and many others as well, the concept cannot be separated from size of plant, and national output totals ignore or hide both plant size and capacity utilization of plants.

Sectors

Comparisons of productivity between sectors (e.g. mining vs. manufacturing in Canada, or mining in Canada vs mining in Chile) are widely used by economists and planners for evaluation of performance and for policy formulation. In the course of discussion of Ken Stollery's presentation, a number of problems of this sort of approach were identified. First, Stollery pointed out that, while data and analysis in broadly-based studies show relationships, they do not show causality, and should not be used as the basis for prescriptions to deal with problems. They can only indicate areas for concern.

He also pointed out some of the pitfalls of aggregating total-factor information over time. In the productivity studies of Dawson and Anton, weights were used in aggregating data. These weights were based on 1961 input-output tables, and resulted in a downward bias, making the mining productivity look even worse than he felt that it should have looked. Selection of beginning and ending points is crucial as well, in that unusual circumstances can cause upward or downward bias. Felske's choice of 1974 as the starting point for a Chilean copper evaluation was criticized, for example, as following a period of chaos which would make the following years look better than they should.

Other Data Problems

Availability of data has been a major stumbling block to assembling useful information on mining productivity. Brian Mackenzie has been assembling data on a deposit-by-deposit basis for his study of exploration productivity. This approach however is extremely time-consuming and expensive, and not appropriate for some researchers or aspects of mining because of problems of confidentiality. Ken Stollery, relying on published Statistics Canada data, encountered problems of interpretation. It was pointed out, for example, that numbers used to identify metal in concentrate actually represented metals paid for (or recovered), a difference that could be significant.

Using either approach, there remains the problem of timeliness. Changes and improvements occurring in the mining industry today will not show up in published figures for several years - and trend analyses will be correspondingly delayed. In many instances the industry is coming out of a trend by the time the trend has been identified, and before policies are in place to deal with it.

Energy, Mines and Resources has data on a mine-by-mine basis that could provide a more accurate basis for aggregation and analysis than Statistics Canada data, but here too there are drawbacks, such as confidentiality problems and shortness of the data series. Industry participants felt that an easing of EMR's restrictions on use of this data would be constructive.

Purpose of Productivity Measurement

It became clear over the course of the discussions that difficulties of data reliability and availability increase with the level of aggregation and with the length of time being evaluated. For individual mines, the problems of productivity measurement are manageable. For intracompany studies, they are more complicated, but still widely used. The example of Ontario Hydro's productivity study, used for a variety of corporate purposes, was cited. Commodity studies are similarily complex but widely used by both companies and governments for policy studies and planning.

Sector or industry-level studies are the most difficult. They are also generally performed by people not directly connected with mining, often using aggregated data, and with little information on how it was aggregated or on intervening variables which will affect the conclusions. In spite of these severe limitations and the possibility for misleading findings, these studies can have a great deal of influence on government policies affecting the mining industry.

Conclusions

Participants generally agreed that the mining industry experienced real problems in recent decades, and that productivity improvement had stagnated in the 1970s. There was also a strong conviction among most that the worst is over, and the trend is in the process of being reversed. It was felt that, in future, mines will be radically different, with smaller workforces, new mining methods, and much better cost control. Even old mines can radically improve their cost-competitiveness.

Continuous productivity improvement is essential, if the full potential of the mining industry is to be realized. These improvements should span all aspects of the industry: management, labour, technology, research and development, transportation, product development etc. High-cost operations must inevitably be closed down, and only competitive operations should continue for the long term. Mines that produce commodities such as potash, uranium, and gold, for which Canada is a relatively low-cost producer, should be emphasized, and the search for new low-cost mines should be pursued, along with exploration for high-grade deposits of other minerals already being produced.

Government policies affecting the mineral industry will continue to play a role in determining the industry's competitive position. Productivity studies which are used as inputs to the policy process should therefore be relevant, accurate, and timely. To this end, it was recommended that studies such as Ken Stollery's should be refined and expanded, with new and more disaggregated data as a starting point. Industry input should be provided, to ensure that the treatment of data and analysis is accurate and appropriate to the special characteristics of the mineral industry. Studies should be as up-to-date as possible, to reflect the recent improvements.

Using such studies as a foundation, it should then be possible to develop an objective and realistic evaluation of the prospect for Canada's competitive position for individual mineral commodities and for the Canadian mineral industry as a whole. Most participants were confident that such an evaluation would demonstrate considerable scope for expanding the economic and social benefits that Canadians derive from mineral-based development.

Afterthought

All seminar participants were given an opportunity to comment on an early draft of the discussions, and a number of extremely useful and thoughtful responses have been incorporated into this published version. In addition, the following thoughts were received from a participant which merit consideration:

First, I do not feel that the seminar addressed itself adequately to technology. It appears that the Inco contributors were the only ones that addressed technology seriously and even there, the VCR mining method was developed by Alan Bauer (cratering studies) and CIL close to 10 years ago. In fact, much of the early VCR method development was done at Inco's Levack mine as I recall, and it seems amazing to me that Inco should have taken so long to transfer it to Copper Cliff and Garson as reported. The obvious question is 'How many other ideas has Inco had that are waiting for the incentive of hard times for use?'. Moreover, this technology has not been hidden, so I wonder how many other companies have used it or could use it.

Second, the case for more studies such as Stollery's is a case for more examination of measures, with no indication that productivity measures are more than an academic exercise. Even for policy use, they can only be directive, not evaluative, but directions are all that policies require anyway. In short, further studies of these measures are merely more expenditures and measures of the sort that the industry does not need.

Third, and possibly a corollary to the first, for either the market development or the technology improvement that is advocated, who will do the research? And where are the research managers? If we take the state of the industry as an indication of its innovative capacity in either technology or markets, then they are not prepared for such development. Similarly, the federal agencies do not have it. I submit that the meeting missed the most basic issue it could have faced: how to develop the people and attitudes on which both technological and market development will depend. Certainly there is nothing in the digest of the discussions to indicate consideration of the area, but I doubt that is an editor's oversight.

The last observation is not original, of course; the mining industry has been developed on the basis of its resources in place (either funds or deposits), not on the basis of its human skills and capabilities. This is not regrettable, if we now accept the fact that the need has changed. We must now learn to develop, use and value wit along with wealth - perhaps even in preference to wealth.

PART I

PRODUCTIVITY MEASUREMENT

CANADIAN MINERAL INDUSTRY
PRODUCTIVITY CHANGE 1957-1979

Kenneth R. Stollery

Introduction

Since the early 1970s an apparent slowdown in the growth of industrial productivity has occurred throughout the industrialized countries. Canada, in fact, has had one of the worst performances, the annual growth of total factor productivity falling from an average of 2.2 percent from 1967-73 to zero since 1974. According to estimates presented here, of all Canadian industries, mining has shown one of the steepest rates of decline and, as we shall see, its productivity decline tended to predate that of other industries, beginning in the middle 1960s instead of post-1973.

There are many possible causes of productivity decline. Several popular hypotheses tested in the study being reported[1] are the effects of energy and other factor price increases, scale economies or the underutilization of capacity, strikes and lockouts, decline in the rate of technological innovation, and, the obvious culprit in depletable industries, the decline in measured productivity by diverting capital from generating output toward pollution abatement, but we shall be able to obtain only indirect evidence for this hypothesis by treating such factors as a residual.

The approach used in the study was to calculate trends in labour and total factor productivity and then attempt to explain these trends by means of the hypotheses just discussed. This was accomplished by estimating a general cost (production) function for the Canadian mining industry as a whole and for several sub-industries. The degree of significance of the measures for the effects of factor price, grade, and scale changes on unit costs reflect the importance of these explanations in the various industries. Finally, a residual productivity measure is calculated for each industry that nets out the effects of these factors and reflects the effects of technical change and other excluded factors.

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[1] The paper is a report on the study Productivity Trends and their Causes in the Canadian Mining Industry 1957-1979, K.R. Stollery, Economic Council of Canada, Discussion Paper No. 248, December 1983.

The paper is divided into several sections. The following section describes the total factor productivity method employed. The third section describes trends in output, mineral grade, and factor shares, and the fourth section calculates trends in total factor productivity and assesses the relative contributions of the factors to the productivity decline. The final part offers tentative conclusions and discusses the limitations of this exploratory research.

Methods of Productivity Measurement

There are two methods for measuring productivity or productivity change: the traditional single factor productivity measure, to determine the output per unit of labour effort for example (e.g. tons per man-shift); and the newer total factor productivity approach which attempts to measure the productivity of all factors taken together. The study described here calculated both productivity measures.

To illustrate, suppose Q represents tons of ore hoisted per time period. In principle, Q is a function of all inputs, say labour, capital and energy, and can be denoted mathematically by $Q = F(L, K, E, t)$ where t as time is a proxy for the effects of new production techniques, environmental controls, and other exogenous effects on productivity. Tons per man-shift (TPMS) in this context is simply Q/L, and will increase as long as $\hat{Q} > \hat{L}$, where the circumflex represents a percentage change. (For example, if output rises at 4 percent with employment only increasing 2 percent, then TPMS rose 2 percent.)

A level index for total factor productivity is less easy to derive, but its change is simply the percentage difference between output growth and that of all inputs; (this difference must have been due to factors such as technological change, for instance). Total factor productivity change is thus symbolically;

$$\widehat{TFP} = \frac{\partial \ln F}{\partial t} = \hat{Q} - \alpha_L \hat{L} = \alpha_K \hat{K} - \alpha_E \hat{E} \qquad (1)$$

where σ_i represent the proportional contributions of each factor, i.e., $\sigma L = \partial \ln F / \partial L$. The reason for employing the total factor productivity approach is that it is less misleading than single factor measures. For example, TPMS may increase due to a higher level of capital equipment, for example, but this will represent a true productivity increase only if the increase is large enough to justify the investment cost of the new machines. The newer method circumvents these problems by looking at all factors together.

A related way of looking at productivity change is through the cost rather than the production side. From this perspective, the natural definition of productivity growth is the (negative) percentage change in costs, holding output constant. If $C = G(Q, P_L, P_K, P_e, g, t)$ represents total costs as a function of output, factor prices, mineral grade and time, then productivity growth from the cost side is:

$$-DCDT = -\frac{\partial \ln C}{\partial t} = -\frac{\partial \ln G(Q, P_L, P_K, P_e, G, T)}{\partial t} \qquad (2)$$

where ln represents the natural logarithm.[2] Because productivity change from the cost side holds output constant, but $\widehat{TFP}$ from the production side does not, the two are not exactly equivalent. If there are economies of scale in production, then TFP can rise solely due to an increase in output. Representing these scale economies by the index SCE, Ohta[3] has shown that:

$$\widehat{TFP} = -DCDT/(1 - SCE) \qquad (3)$$

If costs per unit are independent of output, SCE = 0 and $\widehat{TFP} = -DCDT$. With SCE > 0 as expected in mineral industries, a reduction in cost due to new technology increases productivity directly, as measured by -DCDT, and indirectly through the cost reduction allowed by the fact that the new technology allowed output to expand.

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[2] Two important omissions from the cost function are the price of material inputs and an index of capacity utilization, neither of which were available at the level of aggregation employed in the study. The lack of a materials price forced the use of value added instead of gross output as the output measure; the lack of a CU index was perhaps more serious in attributing to scale economies the effects of underutilized capacity.

[3] M. Ohta, 'A Note on the Quality Between Production and Cost Functions: Rate of Returns to Scale and Rate of Technical Progress', Economic Studies Quarterly 25, 1974, pp. 63-65.

For actual estimation, a specific form for the cost function was required, and the popular translog was employed as being sufficiently general, easily estimated, and relatively parsimonious in parameters. The estimated function with the usual homogeneity restrictions added is shown in the appendix, along with the resulting factor shares in total cost. The estimated scale economies measure and the effect of mineral grade (g) on costs are respectively

$$SCE = 1 - [\theta_Q + \theta_{QQ}\ \ln Q + \theta_{Qg}\ \ln g + \theta_{tQ}\ \ln t + \sum_i \gamma_{Qi} \ln P_i] \quad (4)$$

$$DCDG = \partial \ln C / \partial \ln G = \theta_g + \theta_{gg}\ \ln g + \theta_{Qg}\ \ln Q + \sum_i \gamma_{gi}\ \ln P_i \quad (5)$$

and productivity decline from the cost side is:

$$DCDT = \theta_t + \theta_{tQ}\ \ln Q + \Sigma\ \gamma_{ti}\ \ln P_i \quad (6)$$

depending on output and factor prices with the θ_s and γ_s as coefficients to be estimated. Testing the effect of energy prices, on productivity change for example, amounts to a statistical test of the coefficient γ_{tE} associated with the log of the energy price. After estimating the cost function, overall productivity change can then be separated into that due to scale economies, technological change, or grade decline. After a brief review of mineral industry trends in the following section, the results of applying this model are shown for several Canadian mineral industries.

Trends in Mineral Industry Technology and Factor Shares

The mineral industries employed were selected on the basis of data availability and the nature of the production process. Of the industry series available in the major data source (General Review of the Mineral Industries, Statistics Canada), nine were selected:

- asbestos and total nonmetals;
- copper-gold-silver;
- gold;
- silver-lead-zinc;
- nickel-copper;

- iron;
- total metal mines;
- total mines, quarries and oil wells.

As we shall see, data on a disaggregated industry basis is necessary in mining because of significant differences in productivity between industries.

The major activities in mining are the hoisting of ores, from either open-pit or underground mines, and the subsequent milling of these ores to form a powder of higher metal content called a concentrate. The smelting and refining of this concentrate to a metal almost 100 percent pure are further processes classified to manufacturing. There were significant technological advances in both mining and milling during the late 1950s and early 1960s in Canada, but there appears to be a consensus within the industry that the pace of innovation has slowed since that time.[4]

Most innovations have been closely related to scale increases in both underground and open-pit mines. Briefly described, the major changes in underground mining were the introduction of more powerful explosives, large self-propelled drills, and the load-haul-dump (LHD) ore-handling machine. The major advance in open-pit mining was the introduction of larger and larger dump trucks, increasing from between 22 and 34 tons in the 1950s to about 170 tons today, at which size the scale economies appear to have become exhausted. In milling, the major change was the increase in the size of flotation cells.

The recent slowdown in innovation appears partly exogenous, partly related to the exhaustion of scale economies, and partly related to a shift in emphasis toward reducing energy costs, improving working conditions, and abating environmental damage in conformity with noise, vibration, air and water pollution standards.

The period of rapid scale-increasing innovation was marked by a rapid increase in capital per employed worker across all mining industries, as shown in table 1 by the increase in capital's cost share, S_K^*, and by the growth in K/L. Indeed, while showing some modest growth in the

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4. For a fuller description of technical change in Canadian mining see: C.H. Pye, Profitability in the Canadian Mineral Industry, (Kingston: Centre for Resource Studies, 1981); or K.R. Stollery, Productivity Trends and their Causes in the Canadian Mining Industry 1957-1979.

1966-70 period, the table shows that since 1971 average yearly percentage employment growth, denoted by $\hat{L}$, has been virtually nil in all industries except iron.[5] The substitution of capital for labour apparently did not take place as the result of changes in relative factor prices, as labour costs relative to the calculated rental rate of capital(P_L/P_K) decline over the period. Instead, it appears to have been the result of energy-capital complementarity (discussed in the following section), coupled with declining relative energy prices, declines in mineral grade necessitating more capital- and energy-intensive milling, and factor-biased technological change.

The extent of decline in calculated mineral yield or grade is illustrated in table 2, which also shows changes in output, single factor productivities, (Q/L or TPMS) and average costs. Whether grades have declined in Canadian mining is a controversial question, because of the difficulty of estimating grade in complex base metal ores containing several minerals. The problem in nickel-copper mines for example is that, if nickel grade declined while that of copper increased, the nickel-copper grade index will rise or fall, depending on the weight assigned to each. The seemingly plausible method of weighting by prices of the minerals does not circumvent the problem because of the arbitrary nature of the year to be picked as a base. Instead, the method employed was to simply weight all base metals equally and ignore precious byproducts. Clearly, this is imperfect and a better solution must be found. The results for base metals must therefore be qualified. This problem does not arise in the case of single-mineral industries such as iron, gold or asbestos.

There appear to be exogenous trends in energy use independent of grade or technological change. The shift in product mix in the iron ore industry toward agglomerated and direct-reduced ore has greatly increased the use of energy. Environmental legislation such as the Water Act of 1969-70, the Clean Air Act of 1971, and the Environmental

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[5] There has been some shift within the total mining employment from production to salaried workers. According to MacMillan et al., the proportion of salaried workers rose from 10 percent of the total in 1948 to 26 percent in 1973. Unfortunately these data were unavailable on a disaggregated or even yearly basis. J. MacMillan, G.S. Gislason, and S. Lyon, Human Resources in Canadian Mining, (Kingston: Centre for Resource Studies, 1977), p. 16.

Contaminants Act of 1974-76 meant additional consumption of energy. For example, emission controls entail more electricity use in iron mining, effluent standards increase energy use where large volumes of water are involved (e.g. for washing and flotation), and land reclamation increases the handling of waste rock.[6]

Any increase in energy use without a proportional increase in mineral output reduces energy productivity, and according to table 3 this has in fact happened in all industries except nonmetals. While capital productivity has similarly fallen, reflecting the greater capital intensity, the productivity of labour has risen in every industry except gold and nickel as the relative use of labour has declined. The failure of increased labour productivity to compensate for the productivity decline of the other factors is evidenced by the rapid increase in cost per unit of output over the sample period.

Factor Demands and Estimated Productivity Change

Table 3 shows estimated elasticities of demand for the factors in the model. With the exception of silver, where the estimated own-price elasticity of capital demand is wrong-signed, the regularity conditions for the estimated cost functions are satisfied in all sectors.[7] As one would expect, demand elasticities for capital are lower, in general, than for either labour or energy, reflecting the difficulty of rapidly adjusting the capital stock. The fact that energy demand has generally insignificant elasticity is not surprising, given little change in energy prices over most of the sample (up to 1974). The magnitudes shown imply, for example, that a 10-percent increase in wages will tend to reduce overall mining employment by 3.35 percent, as the industry substitutes capital and energy for labour. If output remains constant, this will also raise labour productivity (TPMS) by the same amount, but of course the productivities of capital and energy will fall.

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[6] See B. Gelb, J. Pliskin and M. Wehle, Energy Use in Mining: Patterns and Prospects, (Cambridge: Ballinger, 1979).

[7] For the estimated cost function to represent the dual to a well-behaved neoclassical production function, it is necessary and sufficient that all estimated factor shares be positive for every observation and that own-price elasticities of factor demand be nonpositive. This was true with the aforementioned exception of silver (the labour demand elasticity for gold being statistically zero).

This pattern of interaction between the factors of production is quite consistent across the different sectors. Capital and energy tend to be relatively weakly complementary factors, while labour is quite a strong substitute for both energy and capital.[8] The result is quite as expected from the previous discussion of mineral industry technology, the major energy use in mining taking place in the heavily capital-intensive process of concentration of the mineral ores. Thus from the cross elasticity of energy on labour, a 10-percent increase in energy prices is predicted to reduce labour productivity or TPMS by 6.1 percent in overall mining and 8.3 percent in metals. This strong substitution of energy for labour, at least prior to the 1974 energy crisis, is one of the main findings of the study. It appears that this increased energy use was not a consequence of the decline in relative energy prices before 1974, as the own-price demand elasticities for energy are insignificant. Instead, it was the result of the substitution of both capital and energy for labour in an industry-wide effort to economize on the wage bill.

Trends in Total Factor Productivity

Calculated scale economies (SCE) as well as estimated DCDG, DCDT, and measures of percentage change in total factor

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8. Two exceptions to the general pattern are the significantly negative cross-elasticity for labour on capital in silver-lead-zinc, and the apparent substitutability of capital and energy in total mining in contrast with its sub-industries. The first observation can be discounted since, as previously mentioned, silver did not satisfy the regularity conditions for the cost function. The weak positive capital-energy substitution in total mining (also found by Smithson et al.) is surprising although not inconsistent with the sub-industry results, since the coefficient is not a weighted average of those for sub-industries but was estimated from aggregated data. It may result, for example, from changes in sub-industry shares. See C.W. Smithson, G.A. Anders, W.P. Gramm, and S.C. Maurice, Factor Substitution and Biased Technical Change in the Canadian Mining Industry, Ontario Ministry of Natural Resources, Technical Report, 1977.

productivity (PROD1 and PROD2) are shown in table 4. According to the model, SCE > 0 implies large and significant scale economies in most mineral industries.[9] Although this is according to expectations, the magnitudes of these calculated measures are in some instances too large to be believable. A level of SCE equal to unity, for example, implies that total costs are independent of output and the long-run average cost curve is a rectangular hyperbola.

There are several possible sources of bias for SCE. In the first place, due to the lack of a capacity utilization measure (see footnote 2) it is almost certain that the effects of underutilized capacity rather than scale economies are being attributed to SCE, especially in the post-1971 period of output decline. The omission of materials may be a source of bias, although the study by Smithson et al. indicated that weak separability of ore from other inputs could not be rejected. Another problem may be our specification of the model in static form instead of allowing a gradual change in the capital stock, a possible misspecification made more likely by the presence of autocorrelation as described in the appendix. On the other hand, a recent study by Rao and Preston confirms the presence of strong scale economies in mining.[10] It is interesting to note that in some industries the estimated scale economies appear to have been exhausted by the 1970s, SCE even changing sign in nickel-copper, for example. This appears to be a cause of decline in primal multifactor productivity in such industries, as discussed shortly.

The effects of changes in mineral grade on mining costs are denoted by DCDG. A negative value for DCDG that is statistically significant (the associated t value roughly exceeding 2 in absolute value) implies that costs have been increased (and total factor productivity reduced) by grade decline. DCDG appears significant in nonmetals, copper-gold-silver, gold, and silver-lead-zinc, while remaining insignificant in asbestos, nickel-copper, iron, metal and total mining. Of course these results depend on the validity of the grade calculations for multi-mineral industries in the first place. The true significance of the negative value of DCDG in copper-gold-silver and silver-lead-zinc mines is thus open to some doubt. On the other hand, one may take some assurance from the implication that changes in grade in single-mineral industries such as asbestos have yet had little irreversible effect on cost.[11]

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[9] A much better estimate of scale economies would, of course, be obtained by a combination of time series analysis with a cross-section of different sized mines. Cost data for a large number of mines are available yearly in the Canadian Mining Journal, Reference Manual and Buyer's Guide, but there are no corresponding capital stock estimates at this level of disaggregation.

[10] P.S. Rao and R.S. Preston, 'Inter-Factor Substitution, Returns to Scale, and Total Factor Productivity Growth'. Economic Council of Canada, mimeo, 1982.

The calculations of multifactor productivity from the cost and the production functions (dual and primal measures) are shown respectively as DCDT and PROD2.[12] These are as defined by equations (2) and (3). PROD1 for comparison is the simple Divisia index calculated on the assumption of constant returns to scale, perfect competition, and short-run profit maximization. The rates of change in cost (DCDT) show productivity decline by the 1970s in all industries except gold and silver, even after the effect of the decline in grade has been accounted for. This decline must therefore have been due to the slowdown in technological innovation, increased environmental protection legislation, or other residual factors.

Somewhat disturbing is the indication that in some industries productivity apparently declined during even the 1957-65 period, contrary to expectations. In effect, cost reductions in these years were attributed by the model to scale economies rather than disembodied technical change. As previously noted, there is, in fact, a close association between these phenomena. The result obtained is, however, probably due to the constraint imposed on the model by the fact that the rate of cost diminution depends only on output and relative prices, and cannot vary independently with time (equation 6). In most industries, the coefficient representing the disembodied effects of technology, θ_t, was in fact insignificant, the significantly positive value of DCDT resulting only from the combination of changes in income, factor prices, and technology.

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[11] The results in nonmetals, metal mining, and total mining may also have been affected by the proxies used for mineral grade in these aggregative industries. See the notes for table 2.

[12] The averages shown in table 4 do not identify the beginning of productivity decline in each industry. For the estimated primal productivity measure PROD2, this was 1967 in asbestos, 1967 in nonmetals, 1958 in copper, 1957 in iron, 1964 in silver, 1959 in metals, and 1966 in total mining.

In any case, most industries showed the expected pattern of primal productivity change (PROD2), because the very high estimated scale economies counteracted the dual productivity decline in the calculation of the productivity index. As

$$\text{PROD2} = \hat{\text{TFP}} = -\text{DCDT}/(1 - \text{SCE}), \tag{7}$$

the large values of estimated scale economies tended, however, to magnify the effects of any change in DCDT, resulting in irregular changes in PROD2 for individual years.

Because there have been long and bitter strikes in many mineral industries, notably the Inco strikes in 1969 and 1979 and iron ore industry strikes in 1969, 1972 and 1978, it was thought that short-term variations in productivity would be related to this factor. Regressions for each industry of PROD2 on current and past working days lost to strikes, however, showed no relationship in any industry except gold, where 30 percent of the variation was explained.

As technological change in all industries has been capital- and energy-using, capital and energy cost increases tend to reduce the rate of cost decline (productivity increase), while wage increases tend to enhance it. These effects are empirically small, however; a 1-percent capital cost increase in overall metal mining tends to reduce dual productivity growth by only about 3 percent of the original rate, as from 3.5 percent to 3.4 percent. Instead, the rate of productivity decline (DCDT) tended to be either exogenous or to be related to the slowdown in the growth of output.

Conclusions and Limitations of the Study

This paper has presented evidence to indicate a declining trend in multifactor productivity in most mineral industries during the 1970s. Attention has been focused on the roles of increased energy prices, declining ore grade, and lower output accompanied by increasing returns to scale in the productivity decline. The model also provided estimates of factor demand and substitution possibilities among factors in response to factor price changes.

With reference to the factor relationships in mining, labour was found in all industries to be a strong substitute for energy, and to be weakly substitutable for capital in all industries except silver and gold, a finding that parallels that of the studies by Smithson et al. and by Rao and Preston (labour-capital substitutes). With the exception of total mining, capital and energy were found to be weak complements. Energy price increases apparently result in a significant substitution of labour for energy, and wage increases have the opposite result. The most important trend throughout the sample period has been the substitution of capital and energy for labour, tending to raise labour productivity, although not markedly, and to lower the productivities of both capital and energy.

There may have been some effect on productivity associated with decline in mineral yields, although this is quite speculative, especially when one takes into consideration the difficulties of calculating grade in multi-metal ores. The cost effects of grade decline reflect the necessity of greater capital- and energy-intensive processing at a time of greatly increased capital and energy costs.

There seem to have been significant economies of scale in most mineral industries, and a strong correlation between technical improvements and increases in the scale of operations, especially in the 1960s. Although, as previously noted, the model unfortunately could not distinguish between scale economies and the effects of the degree of capacity utilization, it seems likely that one reason for the productivity slump in mining has been the decline in output in several industries in the 1970s, resulting in lower capacity utilization in mines whose scale of operation was much expanded in the 1950s and 1960s.

After taking the factors above into account, there remains a significant unexplained residual decline in productivity which may be attributed to an exogenous slowdown in technological innovation (which does seem to have occurred), changes in taxation, or the effects of the important health, safety, and environmental regulations introduced in mining in the early 1970s. There is independent evidence to indicate inadequate research and development in Canadian mining and mining supply industries, related to the small size of many mining and mining supply firms and to the degree of foreign control.[13] Little is known concerning the importance of environmental regulations for productivity, although a study by Papanicoluou and Mackenzie estimated current regulations to have reduced base metal mine investment by 3 to 10 percent.[14] An effect of similar magnitude was predicted by Smithson et al., who also estimated a 20 to 26 percent reduction in investment as a result of post-Carter-Commission tax changes. Since technological change is capital-using, a slowdown in capital formation indirectly affects measured productivity growth.

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[13] P.R. Richardson, et al., The Role of Innovation in the Mining and Mining Supply Industries, MT 146, Energy, Mines and Resources, 1976.

The major limitations of the study have to do with possible inaccuracies in the underlying data base and in the assumptions made to facilitate the analysis. The problems associated with estimating mineral grade in multi-mineral industries have already been mentioned and an adequate method of dealing with these problems is still to be devised. The methods used by Statistics Canada to calculate the mineral output series used as the basis for the productivity analysis contain possibly questionable assumptions. The probable overestimation of scale economies due to lack of a capacity utilization measure will certainly have biased the total factor productivity change measures, although decline still shows in both PROD1 (assuming constant returns to scale and thus unaffected by SCE) and in most single factor productivities. Finally, to constrain the parameter estimation it was assumed that mining firms continuously minimized costs, while in fact from casual observation it appears that the effort applied to cost-cutting varies quite dramatically with general economic conditions; firms were much more cost-conscious in 1982-83 than in periods of high mineral prices, such as 1979. Adding such a concept of 'X-efficiency' to an analysis ending in 1979 implies an overestimate of productivity decline because of artificially inflated end-period costs.

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[14] N.A. Papanicoluou and B.W. Mackenzie, Water Pollution Control Costs, (Kingston: Centre for Resource Studies, 1981).

Appendix I   Estimated Cost Functions

This appendix lists statistical results for the estimated cost functions in the different mineral industries. Because the capital, labour and energy shares sum to unity, only two share equations were necessary to estimate, as well as the overall cost function. The estimated equations with the homogeneity restrictions included and errors added are:

$$S_K^* = \delta_K + \gamma_{tK} t + \gamma_{QK} \ln Q + \gamma_{gK} \ln g + \gamma_{KK} \ln(P_K/P_E) + \gamma_{KL} \ln(P_L/P_E) + u_K$$

$$S_L^* = \delta_L + \gamma_{tL} t + \gamma_{QL} \ln Q + \gamma_{gL} \ln g + \gamma_{KL} \ln(P_K/P_E) + \gamma_{LL} \ln(P_L/P_E) + u_L$$

$$\begin{aligned} \ln(C/P_E) = {} & \theta_0 + \theta_Q \ln Q + \tfrac{1}{2}\, \theta_{QQ} (\ln Q)^2 + \theta_g \ln g + \tfrac{1}{2}\, \theta_{gg} (\ln g)^2 \\ & + \theta_{Qg} \ln Q \ln g + \theta_t t + \theta_{tQ} t \ln Q + \sum_i^{K,L} \delta_i \ln(P_i/P_E) \\ & + \frac{1}{2} \sum_i^{K,L} \sum_j \gamma_{ij} \ln(P_i/P_E) \ln(P_j/P_E) + \sum_i^{K,L} \gamma_{ti}\, t \ln(P_i/P_E) \\ & + \sum_i^{K,L} \gamma_{Qi} \ln Q \ln(P_i/P_E) + \sum_i^{K,L} \gamma_{gi} \ln g \ln(P_i/P_E) + u_c \end{aligned}$$

These equations are interdependent; in particular, the error terms for the share equations would be expected to be related to that of the cost equation. The estimation method used was consequently that of full-information maximum likelihood which takes the error correlation into account. The estimation was performed with the TROLL econometrics package from MIT, using the Davidon-Fletcher-Powell computational algorithm for non-linear estimation.

Empirical Results

The results of the estimation are shown in table 5. Multicollinearity in general was not a problem, the correlations between independent variables seldom exceeding .50. In general, output growth was not homothetic, but labour using, as evidenced by the positive γ_{QL} and negative γ_{QK} coefficients. Grade decline had the opposite effect, increasing the use of capital (and energy) by requiring more processing. The positive γ_{tK} and negative γ_{tL} coefficients indicate technological change that is capital using, and θ_{tQ} shows the positive relationship of output growth with technical change.

One statistical problem was the significant positive autocorrelation present in several industries. In OLS estimation it is well known that autocorrelation does not bias the coefficient estimates but tends to increase their standard errors, as well as biasing the adjusted $\bar{R}^2$ statistic. With nonlinear FIML estimation the effects are not known. However, it was not possible to employ the standard generalized least-squares correction techniques for autocorrelation in conjunction with the simultaneous nonlinear maximum-likelihood technique employed in the estimation.

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Table 1

FACTOR USE AND SUBSTITUTION IN CANADIAN MINERALS: 1957-79

	Time Period	Industry			
		Asbestos	Nonmetals	Copper	Gold
S_K^*	1957-65	.211	.406	.306	.112
	66-70	.356	.603	.441	.222
	71-79	.450	.670	.588	.337
S_L^*	57-65	.659	.488	.616	.802
	66-70	.536	.322	.491	.701
	71-79	.447	.260	.347	.593
S_E^*	57-65	.129	.105	.078	.086
	66-70	.108	.075	.068	.077
	71-79	.103	.070	.065	.070
K/L	57-65	1.000	1.000	1.000	1.000
	66-70	1.631	1.564	1.482	1.534
	71-79	2.622	2.631	2.944	3.172
$\hat{K}$	57-65	.079	.079	.023	-.016
	66-70	.081	.154	.171	.023
	71-79	.061	.046	.088	.031
$\hat{L}$	57-65	-.013	.006	.018	-.015
	66-70	.032	.045	.044	-.119
	71-79	.006	.013	.019	-.047
$\hat{E}$	57-65	.058	.066	.067	-.002
	66-70	.063	.071	.137	-.078
	71-79	.023	.034	.042	-.028
P_L/P_K	57-65	1.000	1.000	1.000	1.000
	66-70	.794	.814	.818	.675
	71-79	.834	.846	.858	.759
P_L/P_E	57-65	1.000	1.000	1.000	1.000
	66-70	1.397	1.289	1.415	1.723
	71-79	1.378	1.311	1.847	1.308
P_E/P_K	57-65	1.000	1.000	1.000	1.000
	66-70	.570	.630	.587	.604
	71-79	.600	.657	.465	.591

Note: Copper refers to copper-gold-silver, silver to silver-lead-zinc and nickel to nickel-copper mines.

Industry				
Silver	Nickel	Iron	Metals	Mining
.344	.241	.461	.327	.458
.483	.299	.559	.439	.651
.502	.360	.556	.518	.726
.580	.713	.456	.601	.467
.444	.666	.333	.488	.284
.417	.591	.324	.403	.207
.076	.045	.083	.072	.074
.073	.035	.108	.073	.064
.081	.048	.120	.078	.066
1.000	1.000	1.000	1.000	1.000
1.473	1.074	1.322	1.322	1.773
1.751	1.442	1.401	2.034	2.212
.037	.039	.140	.052	.082
.107	.121	.047	.057	.065
.017	-.002	-.001	.063	.063
-.007	.026	.045	-.003	.007
.038	.067	-.007	.018	.006
.007	-.079	.040	.001	.005
.109	.020	.202	.081	.063
.100	.161	.070	.082	.081
.016	.023	.045	.039	.056
1.000	1.000	1.000	1.000	1.000
.801	.606	.830	.807	1.766
.865	.790	.849	.850	.604
1.000	1.000	1.000	1.000	1.000
1.713	1.386	1.507	1.515	1.295
1.762	1.469	1.501	1.655	1.304
1.000	1.000	1.000	1.000	1.000
.438	.584	.557	.538	.511
.482	.558	.527	.517	.464

Data sources are described in Stollery (1983).

Table 2

OUTPUT GROWTH AND SINGLE FACTOR PRODUCTIVITIES

		Industry			
		Asbestos	Nonmetals	Copper	Gold
$\hat{Q}$	1957-65	.043	.082	.037	-.044
	66-70	.029	.074	.087	-.081
	71-79	-.005	.029	.011	-.066
$\hat{Q}$ORE	57-65	.099	.034	.153	-.023
	66-70	.107	.040	.102	-.087
	71-79	-.106	.056	.115	-.022
Mineral Yield (Grade) (%)	57-65	3.274	3.274	1.573	.259
	66-70	2.020	2.020	1.206	.239
	71-79	1.884	1.817	.628	.203
Q/K	57-65	1.000	1.000	1.000	1.000
	66-70	.745	.753	.876	.643
	71-79	.442	.617	.435	.316
Q/L	57-65	1.000	1.000	1.000	1.000
	66-70	1.241	1.362	1.255	.963
	71-79	1.154	1.614	1.283	.973
Q/E	57-65	1.000	1.000	1.000	1.000
	66-70	.865	1.001	.825	.853
	71-79	.718	1.044	.481	.702
AC=TC/Q	57-65	1.000	1.000	1.000	1.000
	66-70	1.363	1.612	1.492	1.411
	71-79	4.565	3.063	3.834	3.763
AC=TC/QORE	57-65	1.000	1.000	1.000	1.000
	66-70	1.405	1.601	1.491	1.435
	71-79	3.689	2.890	3.827	3.416

Note: Gold grade is in oz./ton.
The grade for asbestos was taken as a proxy for that of total non-metals. The grade for metal mining is an index (1961 = 1.0) of the grades in the different industries. The grade index (1961 = 1) for

Industry				
Silver	Nickel	Iron	Metals	Mining
.089	.084	.163	.023	.057
.046	-.006	-.061	.060	.067
-.019	-.057	.045	-.022	-.007
.052	.029	.152	.085	.085
.089	.069	.039	.069	.055
.012	-.127	-.003	.049	.052
8.599	1.924	.664	.959	1.463
8.538	1.615	.522	.725	.693
6.896	1.831	.467	.694	.656
1.000	1.000	1.000	1.000	1.000
1.034	.717	.908	.887	.906
.783	.427	.696	.598	.717
1.000	1.000	1.000	1.000	1.000
1.482	.744	1.244	1.211	1.605
1.344	.573	1.001	1.263	1.594
1.000	1.000	1.000	1.000	1.000
.617	.654	.474	.631	.708
.499	.312	.342	.474	.593
1.000	1.000	1.000	1.000	1.000
1.263	2.154	1.663	1.454	1.332
3.092	5.214	3.803	3.182	3.031
1.000	1.000	1.000	1.000	1.000
2.657	2.128	1.659	1.469	1.331
5.347	5.167	3.628	2.972	2.392

total mining is an unweighted average of the metal mining grade index and a similar index of grade for nonmetals. For methods of grade calculation and other data see Stollery (1983).

Table 3

SELECTED INPUT DEMAND ELASTICITIES

(Effects of prices on factor productivity; t values in parentheses)

	Industry		
Elasticities at Means	Asbestos	Nonmetals	Copper
Own-price elasticity:			
Labour	-.260	-.332	-.130
	(-.317)	(-.38)	(-1.4)
Capital	-.151	-.051	-.022
	(-2.1)	(-.4)	(-.3)
Energy	-3.94	-.822	-.263
	(-.6)	(-1.1)	(-.2)
Cross elasticities:			
Labour on capital	.161	.100	.063
	(2.5)	(1.2)	(.7)
Energy on capital	-.039	-1.58	-.208
	(-.4)	(-1.3)	(-1.9)
Energy on labour	.433	.980	.471
	(2.8)	(5.3)	(3.7)
Labour on energy	.099	.181	.061
	(2.8)	(5.3)	(3.7)

Industry					
Nickel	Gold	Iron	Silver	Metals	Mining
-1.53 (-1.6)	.010 (.04)	-.611 (-45.5)	-.003 (-.04)	-.211 (-3.4)	-.335 (-4.9)
-.287 (-1.7)	-.003 (-.04)	-.135 (-2.4)	.293 (2.8)	-0.42 (-.5)	-.135 (-3.7)
-.162 (-.1)	-.140 (-.1)	-1.299 (-.17)	-.607 (-.7)	-.540 (-.7)	-.668 (-1.3)
.140 (1.6)	-.062 (.4)	.215 (2.4)	-.178 (-2.4)	.087 (1.5)	.200 (2.3)
-.008 (-.03)	-.116 (-1.8)	-.197 (-.9)	-.507 (-2.9)	-.281 (-1.5)	.086 (1.0)
.170 (.6)	.213 (1.4)	1.497 (4.9)	1.073 (8.4)	.821 (3.8)	.612 (8.4)
.013 (.6)	.051 (1.4)	.395 (4.9)	.187 (8.4)	.123 (3.8)	.152 (8.4)

Table 4

CALCULATED PRODUCTIVITY MEASURES 1957-79
(t values in parenthesis)

Statistic		Industry		
		Asbestos	Nonmetals	Copper
SCE	57-65	1.034 (10.0)	.025 (.26)	-1.513 (-3.6)
	66-70	.916 (4.8)	.168 (.9)	-.279 (-1.3)
	71-79	.637 (5.5)	-.143 (-.7)	-.691 (-2.8)
DCDG	57-65	-.034 (-.1)	-.458 (-8.7)	.382 (1.7)
	66-70	-.067 (-.3)	.002 (.07)	-.476 (-2,4)
	71-79	-.064 (-.3)	-.109 (-6.4)	-.732 (-5.5)
DCDT	57-65	.026 (6.0)	-.043 (-4.3)	.014 (.9)
	66-70	.044 (7.4)	.013 (1.3)	.030 (2.0)
	71-79	.043 (10.6)	.040 (3.6)	.036 (2.4)
PROD1	57-65	.027	.034	.013
	66-70	-.024	-.037	.002
	71-79	-.039	-.003	-.053
PROD2	57-65	.263	.038	-.006
	66-70	.103	-.016	-.039
	71-79	-.105	-.031	-.019

Industry					
Nickel	Gold	Iron	Silver	Metals	Mining
.974	.329	.771	.204	.961	1.183
(5.0)	(2.0)	(9.1)	(3.1)	(4.5)	(2.1)
.999	.270	.855	.496	1.093	.779
(4.8)	(1.8)	(13.0)	(7.2)	(5.7)	(1.3)
-.592	.182	1.051	.476	.726	.933
(-2.2)	(1.0)	(12.2)	(3.6)	(4.0)	(1.7)
.410	.465	-.289	-1.597	-.094	.756
(.3)	(1.0)	(-1.8)	(-7.8)	(-.03)	(.9)
-.449	-.377	-.090	-.619	-.435	1.244
(-.3)	(-.8)	(-.4)	(-5.2)	(-.1)	(1.3)
-.328	-1.257	-.021	-.931	-.266	.863
(-.2)	(-2.6)	(-.1)	(-8.6)	(-.03)	(1.1)
.054	-.003	.050	.002	.018	.078
(10.0)	(-.3)	(7.5)	(.01)	(1.4)	(4.0)
.060	-.004	.038	.013	.032	.063
(9.8)	(-.4)	(9.8)	(.07)	(3.0)	(3.6)
.042	-.002	.038	.009	.035	.058
(12.8)	(-.2)	(9.6)	(.05)	(3.2)	(3.6)
.024	-.030	.047	.070	.006	.012
-.095	.002	-.076	-.029	-.019	.035
-.015	-.053	.005	-.030	-.044	-.056
.184	.005	-.234	-.002	-.033	.344
.070	.005	-.144	-.028	-.070	-.226
.009	.002	.256	-.053	-.013	-.312

Table 5

ESTIMATED TRANSLOG COST FUNCTION PARAMETERS
1957-79
(t statistics in parenthesis)

Parameter	Asbestos	Nonmetals	Copper	Gold
δ_K	3.11 (7.2)	2.70 (9.8)	3.07 (4.2)	2.39 (26.2)
γ_{KK}	.18 (5.4)	.21 (7.1)	.22 (4.7)	.08 (2.9)
γ_{KL}	-.13 (-4.4)	-.15 (-6.4)	-.17 (-3.7)	-.07 (-2.4)
γ_{QK}	-.13 (-4.7)	.08 (.9)	-.01 (-.3)	-.27 (-5.1)
γ_{gK}	-.04 (-3.2)	-.03 (-3.2)	-.09 (-2.4)	.07 (1.0)
δ_L	-1.12 (-2.9)	-1.12 (-4.4)	-1.28 (-1.8)	-.93 (-8.3)
θ_t	-.02 (-.2)	-.35 (-5.1)	-.08 (-.4)	-.04 (-1.0)
γ_{LL}	.13 (4.3)	.10 (3.0)	.17 (3.8)	.12 (3.4)
γ_{QL}	.09 (3.4)	-.08 (-1.1)	.01 (.1)	.24 (4.6)
γ_{gL}	.04 (3.9)	.01 (2.5)	.09 (2.5)	-.07 (-1.0)
θ_0	27.21 (2.1)	11.94 (3.1)	-43.66 (-1.1)	8.10 (50.1)
θ_Q	1.39 (.3)	6.99 (6.4)	18.83 (1.8)	4.02 (27.3)
θ_{QQ}	-.73 (-.6)	-1.25 (-4.1)	-2.41 (-1.8)	-.80 (-6.0)
θ_g	-.002 (-.003)	-1.13 (-4.5)	8.50 (1.9)	-9.35 (-57.8)
θ_{gg}	-.0006 (-.003)	-.65 (-7.2)	-.93 (-1.2)	-.87 (-5.4)
θ_{Qg}	-.09 (-.6)	.24 (5.8)	-1.25 (-2.2)	2.07 (15.1)
γ_{tL}	-.01 (-21.1)	-.01 (-3.0)	-.0[illegible] (-3.1)	.002 (.6)
γ_{tK}	.02 (20.2)	.01 (2.7)	.01 (2.6)	-.004 (-1.1)
θ_{tQ}	.05 (2.6)	.10 (8.7)	.03 (.9)	-.003 (-.4)
K-share equation				
$\bar{R}^2$	.979	.884	.907	.956
D.W.	1.23	.25	.54	.47
L-share equation				
$\bar{R}^2$	.979	.895	.910	.947
D.W.	1.37	.24	.52	.47
TCOST equation				
$\bar{R}^2$	.979	.892	.943	.432
D.W.	1.44	.73	1.02	1.00

Silver	Nickel	Iron	Metals	Mining
4.65 (7.4)	1.77 (3.4)	2.73 (6.7)	3.23 (6.5)	2.42 (3.3)
.36 (8.0)	.12 (2.3)	.18 (6.2)	.21 (6.5)	.15 (7.6)
-.29 (-8.1)	-.11 (-1.9)	-.11 (-3.1)	-.16 (-5.7)	-.11 (-6.1)
.01 (.1)	-.10 (-3.1)	.02 (.6)	-.04 (-1.4)	-.0006 (-.003)
-.02 (-.3)	-.004 (-.1)	-.11 (-2.2)	.05 (1.0)	-.36 (-1.5)
-2.72 (-5.7)	-.44 (-.8)	-1.26 (-4.4)	-1.49 (-3.8)	-.95 (-1.5)
-.04 (-.8)	-.03 (-1.2)	.18 (3.2)	-.05 (-0.4)	.28 (2.4)
.24 (7.8)	.13 (2.0)	.001 (.2)	.14 (4.4)	.09 (5.2)
-.02 (-.8)	.12 (3.4)	-.03 (-1.2)	.05 (1.8)	.007 (.1)
.01 (.2)	.001 (.02)	.09 (2.7)	-.004 (-.1)	.36 (1.8)
45.44 (8.0)	23.81 (6.3)	29.00 (6.1)	70.60 (2.5)	28.21 (1.6)
-.15 (-.1)	.78 (.3)	-.78 (-.5)	-16.32 (-1.3)	.35 (.04)
-.60 (-3.2)	-3.05 (-2.5)	.27 (.8)	3.45 (1.3)	-.05 (-.02)
-5.96 (-3.6)	-8.62 (-2.5)	-2.23 (.8)	-22.69 (-2.4)	4.33 (.4)
-.96 (-2.0)	6.16 (2.0)	-.53 (.8)	6.74 (3.0)	-2.98 (-.6)
1.51 (5.3)	3.40 (2.2)	.10 (.2)	5.19 (2.5)	-1.64 (-.7)
-.01 (-2.9)	-.01 (-6.5)	-.003 (-2.5)	-.01 (-19.3)	-.01 (-2.0)
.004 (1.5)	.01 (5.6)	.0008 (.5)	.01 (14.8)	.01 (1.3)
.02 (2.3)	.10 (4.4)	-.03 (-2.9)	.04 (1.4)	-.03 (-1.6)
.897	.859	.778	.986	.786
1.18	1.70	1.40	1.42	2.08
.943	.844	.926	.992	.837
1.34	1.56	1.44	2.04	2.02
.992	.791	.969	.974	.409
1.72	1.51	1.21	1.00	2.07

COMMENTS ON K. STOLLERY'S PAPER

Henry L. Martin

Dr. Stollery's paper not only fails to illuminate but actually obscures the picture of mining productivity. To be able to follow it, one is forced to refer to his earlier lengthy discussion paper on this subject prepared for the Economic Council of Canada.[1] Worse, both papers contain the same serious errors in data and analysis, which lead to unfounded conclusions of productivity decline.

My criticism is mostly aimed at Stollery's data selection and use. He has chosen to substantiate his theory with data from Statistics Canada publications. Although Statistics Canada defines its terms, Dr. Stollery's apparent lack of technical expertise in the subject of mining has led him seriously astray in his choice of data and in his interpretation of what the data mean.

For instance, Dr. Stollery measures labour productivity in terms of tons per man-shift by dividing tons of ore hoisted per time period of labour. Unfortunately, he has included in his calculations employees in all directly and indirectly related mining activities at a mine site: mining, processing (milling/concentrating), assembling, storing, inspecting, handling, packing, maintenance and repair, as well as janitors, watchmen and foremen. A random selection of employment data for the year 1978 shows that, for metal mines, there were 28,583 workers employed in mining, and 11,394 workers in milling/concentrating operations (source: Statistics Canada, Metal Mines, 1978), Catalogue 26-223). Miners produce the ore; mill/concentrator workers then process it to form a concentrate in an entirely separate function and plant. Inclusion of the latter in national mine-labour productivity expressed as tons of ore mined per man-shift is a serious error. Stollery's lack of understanding of the distinction between the mining and concentrating processes is illustrated by his erroneous definition of concentrate in his earlier discussion paper, where he stated: 'It might have been more realistic to assume a constraint on ore hoisted from the mine rather than concentrate produced, which is hoisted ore times grade'. (emphasis added)

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[1] K.R. Stollery, Productivity Trends and their Causes in the Canadian Mining Industry 1957-1979, Economic Council of Canada, Discussion Paper No. 248, December 1983.

Labour productivity is further understated by Stollery, especially for the 1971-79 period, because he does not take into account the removal of waste rock at open-pit mining operations. The 1970s witnessed a great increase in ore mined from open-pit porphyry mines. In 1969, such ores amounted to about 19 million tonnes, increasing to about 85 million tonnes by 1979, while nonporphyry nonferrous metal ores mined totalled less than 65 million tonnes during each of these years. The ratio of waste rock to ore for open-pit porphyry mining is of the order of 3 to 1; the labour involved in the removal of increasingly large tonnages of waste rock at these mining operations should be acknowledged. Indeed, the aggregating of underground and open-pit operations, which use entirely different mining methods and scales of operations, does not do justice to the subject of overall productivity trends in mining.

In each of his two papers, Stollery devotes one paragraph to the difficulties of grade determination in multi-metal mines. In his earlier paper, he stated that 'there are no published data on ore grades in Canada through to the 1970s. In fact, mine-by-mine data on ore grades were and are published annually by the Department of Energy, Mines and Resources in its Canadian Minerals Yearbook. On the basis of his own 'solutions' to these problems as he perceived them, Stollery makes many references to declining ore grades as an established fact of importance in productivity decline. On the contrary, ore grades at Canadian base-metal and precious-metal mines do not indicate a declining trend, as is demonstrated by EMR's detailed mine-by-mine analysis of ore production at 10-year intervals, 1939-79, with estimates for 1989.[2]

Dr. Stollery's attempts to document declining ore grades are far off the mark. His table 2, included in both of his papers, shows his data on ore grades, which he terms 'mineral yield (grade) (%)'. As is shown below, grade data in this table and their derivations are illustrative of the magnitude of Stollery's errors in grade determination as well as in his concept of what mining entails.

Ore Grade Determination

Recognizing the problem of multimetal mines, Stollery states that 'the method employed was to simply weigh all these metals equally and ignore precious byproducts'. A more detailed explanation was given in his earlier discussion paper, in which he stated:

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[2] In press, to be included in a volume on international mineral exploration, publication by Resources for the Future, Washington, D.C.

> We have instead followed Pye (1981) in simply summing the total mineral content of nickel-copper concentrates, (emphasis added) for example, in effect giving each metal equal weight. Where there is a major difference in the weights and values of the metals, as in nickel-copper mines that produce precious metals as byproducts, we have simply taken the dominant metals only. The grade shown in table 2 for nickel-copper then reflects the total of nickel and copper (in ?) concentrates. Of course, for single-mineral industries such as gold, iron and asbestos the whole problem disappears.

Let us look at some of the results of this procedure.

Iron

Grade determination is best illustrated by an example. According to EMR, Canadian iron ore production in 1975 amounted to 104 million tonnes of crude ore, with an average iron content of 36.6 percent. This material was concentrated and further processed, with resulting shipments of 44.8 million tonnes of iron ore products with an average iron content of 62.2 percent (source: MR 170 'A summary view of Canadian reserves and additional resources of iron ore', 1977, p. 8). Stollery seems to have equated the tonnages of iron ore products shipped with tonnages of iron in iron ore mined to arrive at his 1971-79 average ore grade of 46.7 percent. Such calculations have no relationship to ore grade.

Metals

Stollery's claim to have followed Pye[3] would indicate that for the 'Metals' grade he divided the total weight of metals in concentrates (copper, nickel, lead, zinc, silver and molybdenum), by the tonnage of ore from copper-gold-silver,

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[3] C.H. Pye, Profitability in the Canadian Mineral Industry, (Kingston: Centre for Resource Studies, 1981).

silver-cobalt, silver-lead-zinc and nickel-copper mines.[4] Furthermore, Stollery devised an index (1961=1.0) of the metal grades in the different industries; there is no explanation of this index in either paper. The rationale for these procedures is difficult to surmise, especially when, for example, a kilogram of silver is deemed equal to a kilogram of lead!

Copper

Under the heading 'Copper-Gold-Silver' mines, Statistics Canada includes copper-zinc and copper-molybdenum mines. In grade determination it is misleading to aggregate all copper mine production because this fails to distinguish between the low-grade, large tonnage porphyry mines mined by open-pit methods and the multi-mineral high-gade smaller operations mined by underground methods. Table 1 summarizes EMR's compilation of mine-by-mine data on ore grades for the two sources:

Table 1

COPPER ORE GRADES

	1960	1969	1979
Porphyry Ores:			
No. of mines	nil	3	9
Ore tonnage mined (million tonnes)	-	7.9	71.0
Copper ore grade	-	0.57%	0.45%
Copper and equivalent grade[a]	-	0.65%	0.68%
Nonporphyry Ores:			
No. of mines	23	41	24
Ore tonnage mined (million tonnes)	13.4	18.0	17.4
Copper ore grade	1.92%	1.64%	1.67%
Copper and equivalent grade[a]	3.34%	2.82%	3.46%

[a] Copper equivalents in copper ores represent associated co-product and byproduct metals in terms of amounts of copper of equal value, using 1979 metal prices for each.

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4. Ibid., p. 81.

Thus, by 1979, economies of scale in large open-pit operations had led to the situation where ore production from porphyry copper deposits was four times greater than that from nonporphyry copper mines, at competitive costs even though the nonporphyry mines had copper grades four times as high along with much higher values in associated metals. The ore mined by open pit contained practically the same amount of copper as the ore mined underground (1979). It was the thrust of technology that allowed this accelerated growth of profitable production during the 1970s from the low-grade porphyry deposits, at comparable costs. These operations clearly indicate that the ore grades of comparable types of copper deposits mined have not declined. Contrary to Stollery's supposition that there seems to have been a slowdown in technological innovation, technology was at the forefront in the expansion of mine production of copper-in-ores during the 1960s and 1970s.

Silver

Stollery's 'Silver' grade of 6.896 percent (silver-lead-zinc mines) for 1971-79 translates into an incredible 2010 troy ounces per short ton or 68,802 grams per tonne.

Asbestos

EMR records show that asbestos ore grades (in terms of recoverable fibres) of ores mined in 1979 at individual asbestos mines ranged from 2.6 percent to 8.6 percent, averaging 5.2 percent. Stollery's asbestos production grade averaging 1.886 percent for 1971-79 is far too low.

Nonmetals

The choice of asbestos grade as a proxy for total nonmetals makes no sense. Asbestos grades and the ore quality of other nonmetals such as potash and salt are clearly not comparable.

The above selection of comments will suffice to convey my rejection of the data, analysis and conclusions presented in Dr. Stollery's paper.

THE PRODUCTIVITY OF CANADA'S MINERAL RESOURCES: IS THE QUALITY DECLINING?

Brian W. Mackenzie

Argument

The future role of the mining sector in Canadian economic development is uncertain. While concerns are increasingly expressed that mining may be a sunset industry, there is little if any factual evidence to support the contention.[1]

Apparently negative mining productivity trends, one basis for this view, are suspect because of suppositions made in productivity studies regarding the changing quality of mineral resources.[2] Until the geological factors which influence the efficiency of mining are adequately understood, real trends in mining productivity will remain a matter of controversy. The mining sector has been too important to the economic prosperity of Canada to consider changes in economic development policy without first understanding these trends.

This paper outlines a procedure for examining the effect of the quality of mineral resources on productivity change in the mining sector, The methodology is applied to evaluate trends in the productivity of Canada's base metal resources.

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1. A 'sunset industry' is characterized by a declining competitive position in international markets and the loss of comparative advantage relative to other sectors of the economy. The idea that mining in Canada may be a sunset industry appears to have arisen most recently in the work of the Macdonald royal commission on the economy and is part of a more general concern about resource-based economic growth. For the mining sector, the notion is based on perceived consequences of the exhaustible nature of mineral resources in terms of time trends in resource quality and mining productivity.
2. Mineral resource quality is considered here to comprise all geological parameters associated with a mineral deposit which affect the economics of mine development and production, including size, grade and location.

Background

There is a widely held belief that the quality of mineral resources systematically declines with time. This conviction, based on the exhaustible nature of minerals, is illustrated by the concept of mining in economic theory. Since mineral deposits are fixed in size and variable in quality, theory presumes that mining activities proceed sequentially from higher to lower quality ores.

The economic consequences of this belief have diverse policy implications. As resource quality declines, the cost of producing minerals increases. Thus, the Club of Rome advanced an argument in the early 1970s that the exhaustion of mineral resources provides a limit to worldwide economic growth and threatens the welfare of mankind.[3] Furthermore, as the cost of producing minerals increases, the comparative advantage in mining deteriorates. This perceived consequence underlies the sunset industry view.

A good deal of circumstantial evidence can be found to support the belief that the quality of mineral resources is declining. There is a powerful economic incentive to sequence mining from higher to lower quality ores wherever possible, a common practice at operating mines. This economic rationale also tends to govern the order of development and exploitation among known mineral deposits. Intensively explored and developed mining districts are typified by increasing mining depths and, often, declining ore grades. Closures of mines and mining communities are inevitable consequences of the exhaustible nature of mineral deposits.[4] Finally, based on its dismal economic performance since 1982, mining in Canada does currently look like a sunset industry. These observations are consistent with the declining rates of efficiency shown in studies of Canadian mining productivity.

However, if we are interested in the role of mining in the long-term economic development of a country like Canada, blessed with a vast, complex, and still largely unknown mineral endowment, there are also grounds for questioning the validity of this widely held belief. First, it is notable that mineral deposits are not only fixed in size and variable in quality, they are also initially unknown. Thus, the mining cycle begins with mineral exploration, a high risk information-gathering process. One consequence of the high risk nature of exploration is that a strong random element is associated with the discovery of mineral deposits. This means that it is not practically possible to find the best deposits first and then proceed systematically to lower quality discoveries. Also, while known mining districts are being more intensively explored, the frontiers of the search process are being extended into new unknown regions. At the same time, advances in geological concepts and exploration technology act to relax the scientific limits of exploration.

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[3] See D.H. Meadows, et al., The Limits to Growth, New York, Universe Books, 1972, 205 pp.

[4] 'Picking up the pieces' has always been a prominent aspect of Canadian mineral policy, from the Emergency Gold Mining Assistance Act and Cape Breton coal subventions, to more recent concerns about Cyprus Anvil, Schefferville, and Lynn Lake.

Under these conditions, it is questionable whether the resource quality revealed by successful exploration, and thus available for mining, declines with time. Indeed, a number of resource-based studies do not support this hypothesis.[5] We see, for example, that Kidd Creek and

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[5] Cranstone shows that the value of minerals discovered in Canada per dollar of exploration expenditure has remained relatively constant since the second world war. See D.A. Cranstone, 'Canadian Mineral Discovery Experience Since World War II', paper presented at International Institute for Applied Systems Analysis, Laxenburg, Austria, December 1983, 64 pp.

A study by Martin and Jen, analyzing the grade of ore extracted from some 800 deposits in Canada over the last 50 years, concludes that average ore grades have improved for some commodities and have shown no signs of decline for others. In the few cases where modest declines are evident, this is found to be attributable to advances in technology enabling the mining of lower grade deposits, rather than to the effects of exhaustion. See H.L. Martin and L.S. Jen, 'Are Ore Grades Declining? The Canadian Experience, 1939-89', paper presented at International Institute for Applied Systems Analysis, Laxenburg, Austria, December 1983, 51 pp.

Mackenzie analyzes the present-day economic viability of 275 base metal deposits discovered in Canada to 1977, classified by discovery dates. The time trend in the average net present value of the deposits which are found to be economic does not in general support

Hemlo, no doubt the highest quality base metal and gold deposits found in Canada to date, neither being remote or deep, were discovered as recently as 1964 and 1981 respectively.

Based on these conflicting observations and evidence, it can only be concluded that we do not presently know the time trend in mineral resource quality. Is the quality of Canada's resources declining and, if so, to what extent? Furthermore, we would like to examine the effect of the changing resource base on mining productivity.

Productivity Measurement

The term 'productivity' encompasses a variety of measures which may be applied to evaluate the efficiency of production.[6] For this purpose, empirical relationships are developed to link production or 'output' with one or more of the required factors of production or 'inputs'. The type of productivity measure used depends on the issue which needs to be addressed.

For government policy analysis, productivity is usually measured in terms of the efficiency with which all factors of production, classically identified as the land (including mineral resources), labour, and capital inputs, are employed in production. This type of indicator is referred to as 'total factor productivity'.

The purpose of productivity studies is to monitor and explain time trends. Based on historical evidence, what has been the direction and rate of productivity change, and why?

Ideally, changes in total factor productivity reflect the extent to which changes in output are not matched by changes in all factor inputs combined. In practice, it may not be possible to assemble time series information for all inputs, thus limiting the realism of the results and the explanatory power of the analysis.

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the hypothesis that the quality of mineral resources is declining. See B.W. Mackenzie, Economic Mineral Exploration Targets, Working Paper 28, Centre for Resource Studies, Kingston, January 1984, 63 pp.

[6] For more detailed information on the concept of productivity, the interested reader is referred to: S. Fabricant, 'Productivity', in International Encyclopedia of the Social Sciences, vol. 12, The Macmillan Company and the Free Press, New York, 1968, pp. 523-536.

Mining Productivity in Canada

Three principal studies have been made of mining productivity in Canada: Dawson[7], Anton[8], and Stollery[9].

Dawson analyzes growth in the Canadian mining sector during the 1947-67 period in relation to the resources required to achieve that growth. Overall results show an average annual increase in productivity of 4.5 percent for the first postwar decade, falling off to less than 0.5 percent in the second decade. Dawson acknowledges several limitations associated with the data base and methodology. Notably, the productivity function is restricted to labour and capital inputs, and therefore the changing quality of mineral resources employed in mining is not considered.

Anton's unpublished study parallels the work of Dawson, extending the time frame to 1972. Overall results indicate that mining productivity in Canada has shown a slight tendency to decline from 1960. The data base is limited to indicators of the labour and capital factors of production. Once again, variations in resource quality are not incorporated in the analysis.

Stollery formulates and applies a more ambitious and theoretically appealing productivity model, intending to obviate some of the limitations of the two earlier studies. For example, ore grades are incorporated in the productivity function. Overall mining sector results for the 1957-65, 1966-70 and 1971-79 intervals indicate a declining trend in total factor productivity, interpreted to be one of the worst and longest-lasting in Canada, beginning in the mid-sixties. A perceived decline in the grades of ore mined is shown to have a significant impact on reducing mining sector efficiency.

However, Stollery's treatment of the mineral resource input has two basic faults. First, ore grade represents only one of several facets of the quality of mineral resources. Second, the definition and measurement of the grade variable employed can at best be described as uninformed.

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[7] Dawson, J., Productivity Change in Canadian Mining Industries, staff study no. 30, Economic Council of Canada, 1971, 61 pp.

[8] Anton, F.R., 'Productivity in the Mineral Industry', preliminary report for the Department of Energy, Mines and Resources, Ottawa, 1973, 259 pp.

[9] Stollery, K.R., Productivity Trends and their Causes in the Canadian Mining Industry, 1957-79, discussion paper no. 248, Economic Council of Canada, December 1983, 86 pp.

An inherent difficulty in measuring mining productivity, well illustrated by these three Canadian studies, is the uncertain, variable and complex character of the mineral resource input. The effect of the changing quality of Canada's mineral resources on mining productivity is not yet understood. Consequently, we do not know the real trends in mining productivity.[10]

The Productivity of Mineral Resources

We wish to examine the effect of the quality of the mineral resource input on productivity change in the mining sector or, in other words, the productivity of mineral resources. While the evaluation procedure adopted measures 'total factor productivity', it differs in several respects from conventional econometric methods, including those used in the mining productivity studies cited.

Mining is a dynamic process. First, the market demand for mineral commodities changes with time. Secondly, the real costs of labour, capital and interindustry inputs vary. Thirdly, depletion, the physical exhaustion of mineral deposits, is inherent in their exploitation. Depletion may cause the cost of mineral supply to rise with time. Finally, advances in technology act to reduce the cost of the mining process. Notably, these dynamic forces are also highly uncertain.

Conventionally, mining productivity studies attempt to analyze the actual combined effect of these dynamic variables and to explain the consequent results. Even though it may not be possible to measure all the factor inputs (as, for example, in the studies of Canadian mining productivity), they are in fact all varying with time.

Productivity change can also be assessed with one or more of the factor inputs held constant, as in an experi-

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10. A recent study by Green of gold mining productivity in Ontario during the 1966-77 period provides an excellent example of the understanding of productivity trends which is possible by careful compilation of statistical data, specifically focused, and comprehensively analyzed and interpreted. See A.G. Green, Productivity and Price: the Case of Gold Mining in Ontario, Working Paper No. 32, Centre for Resource Studies, Kingston, 1983, 46 pp.

ment carried out under controlled conditions. While such a situation does not fully represent actual experience, results may shed light on the influence of a particular input of interest. This approach is adopted in the present study. To isolate and examine the effect of the quality of mineral resources on mining productivity, the other factors of production are valued with reference to a particular point in time, and are, therefore, assumed to remain constant.

More specifically, the methodology adopted differs in the following respects from previous studies of mining productivity in Canada:

- deposit-specific data rather than aggregate government statistics are used;

- information and estimates are defined in cash flow terms instead of accounting terms;

- a discounted cash flow evaluation procedure rather than statistical analysis in the form of an econometric model is utilized;

- no attempt is made to assess overall historical productivity trends. Instead, attention is confined to the effect of changing resource quality on mining productivity;

- a long-term view of the mining sector is adopted, considering time trends in the quality of mineral resources revealed through discovery. Thus, mineral resources are classified on the basis of discovery dates for individual deposits, rather than in terms of when the mining of ores actually takes place;

- all inputs and outputs are measured in constant dollar terms;

- factors of production other than the mineral resource input are evaluated on the basis of a standard set of present-day economic and technological conditions. In this way, all other inputs in the mining production function are held constant.

This evaluation procedure enables us to isolate the changes in mining productivity attributable to depletion effects and to advances in geological concepts and exploration technology, on the basis of observed variations in the quality of mineral resources discovered.

The quality of mineral resources has a number of facets, including:

- deposit size;
- geological grade;
- geographical location;
- ore width;
- depth below surface;
- mineralogical complexity;
- geotechnical properties.

Deposit quality effects the selection of mining and processing methods, recoverable ore reserves, mineral processing recoveries, stripping ratio, scale of operation, sales revenues, and capital and operating costs. Thus, the quality of mineral resources is a critical aspect of mining productivity.

Evaluation Procedure[11]

Using the foregoing precepts, the productivity of mineral resources is assessed here in terms of the average economic return associated with the discovery of an economic mineral deposit. This assessment is based on cash flow estimates for the development and production phases of mineral supply.[12] The evaluation is carried out on a potential value or before-tax basis.[13]

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[11] This study extends a methodology which has been developed at the Centre for Resource Studies over the past decade. For further details of the evaluation procedure, see B.W. Mackenzie and M.L. Bilodeau, Economics of Mineral Exploration in Australia: Guidelines for Corporate Planning and Government Policy, Australian Mineral Foundation, Adelaide, 1984, 171 pp.

[12] Attention is restricted to the development and production phases because the focus is on the quality of mineral resources discovered. A complete assessment of the effect of geological factors associated with the mineral resource input would also have to consider real trends in exploration expenditures. Thus, exploration phase estimates would be included in the determination of mining productivity trends.

[13] We do not consider the application of mining taxation to the overall potential return. Thus, the effect on productivity of how this potential return may be shared between industry and government is not evaluated. However, the potential value level of assessment provides a more basic insight into the productivity of mineral resources.

Potential value is defined as the difference between the revenues realized from mining production and the development capital and production costs required to realize that revenue, including an allowance for the cost of capital. In other words, the potential return from an economic deposit is our way of measuring the relationship between output and inputs in the mining production function.

Assessment of the average return associated with the discovery of an economic deposit is based on the documentation of actual experience over a relevant historical time period. This information is then placed in the context of current outlook conditions to examine the effect of changing resource quality.

One aspect of the evaluation is to determine which of the discoveries made during the selected historical period would be economic under today's conditions. For this purpose, those discoveries made during the historical period which could possibly satisfy the required conditions for an economic deposit are listed for evaluation and a discovery date is estimated for each. Each of the possible economic discoveries is then evaluated to assess the cash flow characteristics which would be associated with its development and production.

General estimates of metal prices and smelter payment terms, together with individual deposit estimates of recoverable ore reserves, mill recovery factors, mine and mill capacity, capital costs, preproduction development period, and operating costs, are used to evaluate a cash-flow distribution for each deposit. The general market estimates reflect current outlook conditions. The individual deposit estimates are made by placing actual historical deposit data in a framework of today's conditions. A number of measures of economic worth, including total revenue and rate of return, are evaluated for each deposit. Those discoveries which satisfy minimum acceptable size and profitability conditions are considered for study purposes to be economic mineral deposits.

The cash flow estimates for all economic deposits are then averaged, resulting in a time distribution of average cash flows for the development and production phases of the mining cycle. A number of productivity measures are derived from this distribution, reflecting the average return characteristics of an economic mineral deposit.

In summary, actual mineral deposits discovered are listed and classified by discovery date, and their particular geological features are appraised. All other aspects of the evaluation procedure are static. The cost of capital is assumed constant. Development- and production-phase cash flows for each of the historical discoveries, apart from the influence of their actual geological characteristics, are evaluated on the basis of a standard set of present-day economic and technological conditions.

Productivity Measures

The productivity measures adopted require enumeration of the number of deposits which, on evaluation, satisfy the specified economic discovery conditions. This total represents the statistical sample size on which the average return characteristics are based.

The quality of mineral resources is then examined, using the following measures of the average or expected return characteristics for an economic deposit:

- expected return from development and production for an economic deposit expressed as a discounted value at the start of development;
- expected rate of return for an economic deposit based on the time distribution of average cash flows from development and production;
- expected size of an economic deposit in terms of ore reserve tonnage;
- expected metal product mix realised from an economic deposit;
- step-by-step assessment of the expected undiscounted development and production phase components of the cash flow for an economic deposit.

The last of these sets of indicators is intended to reveal specific facets of mineral resource quality. The step-by-step procedure, outlined in table 1, expresses results in average or expected dollars per tonne of ore from economic discoveries.

Gross in-situ value, the product of geological grades and metal prices, reflects the expected geological grade of an economic deposit. Mining losses account for the part of geological reserves which inevitably has to be left behind in pillars and remnants. Also, geological grades are diluted by the mining of barren or low-grade waste rock adjacent to the deposit itself. These mining losses are a function of such facets of deposit quality as deposit size, ore width, depth below surface, and geotechnical properties.

Table 1

EXPECTED DEVELOPMENT AND PRODUCTION PHASE COMPONENTS OF THE CASH FLOW FOR AN ECONOMIC DEPOSIT
($ per tonne of ore)

Gross In-Situ Value

Less: Mining Losses
Milling Losses
Smelting and Refining Charges
Concentrate Transportation Costs

Revenue at the Minesite

Less: Pre-Production Capital Expenditures
Production Costs

Potential or Before-Tax Cash Flow

Milling losses evaluate the incomplete recovery of the metal content of the mill feed in the concentrate product. For example, in the milling process, the recoverable ore delivered to the mill, which might contain 2 percent copper and 5 percent zinc, may be upgraded to produce a 20-percent copper concentrate and a 55-percent zinc concentrate, with the loss of 10 percent of the copper content and 20 percent of the zinc content in the tailings. Milling losses depend on the mineralogical characteristics of the deposit.

In determining the value of the concentrate products, smelting and refining charges have to be deducted. The combined effect of these charges may be illustrated by expressing the value of metal contained in the concentrate as a percentage of the refined metal price. Thus, the value of copper in concentrate form might represent 70 percent of the copper price, while 50 percent of the zinc price might be paid for zinc contained in a zinc concentrate. Typically, gold and silver byproducts contained in base metal concentrate realize in the order of 90 percent of their refined prices. Thus, smelting and refining charges are a function of the mix of metals found in a deposit.

Concentrate transportation costs then have to be deducted, as shown in table 1, to work the valuation back to an estimate of revenue at the minesite. Transportation costs depend on the geographical location of a deposit in relation to the smelting facilities.

Revenue at the minesite normally represents the top line of a cash flow calculation associated with the contemplated development of a mineral deposit. The costs associated with producing the concentrate then have to be deducted. These include the pre-production capital expenditures required to develop the necessary capacity and the production costs incurred in operating the mine. Capital and operating costs are a function of virtually all aspects of the quality of the mineral resource input.

The year-by-year deduction of capital and operating cost estimates from revenue at the minesite results in a time distribution of potential or before-tax cash flow. The cash flow distribution is then combined with an estimated cost of capital to derive more complete productivity measures reflecting the average return characteristics for an economic deposit.

Canada's Base Metal Resources[14]

The evaluation procedure developed is now applied to assess time trends in the productivity of Canada's base metal resources.

Base metal resources have played an integral part in the growth and development of mining in Canada. The constituent commodities - copper, zinc, lead, molybdenum, and byproduct gold and silver - require similar exploration, development, and production technologies, and form a consistent grouping in terms of sources of information.

Value of production from the Canadian base metal sector increased from $2.2 billion in 1975 to $4.1 billion in 1980, before the prolonged world-wide recession drove the value down to about $3.0 billion per year in 1982 and 1983. Economic recovery has been hesitant, but a modest upturn in base metal markets is apparent in 1984.

The base metal sector accounts for 40-45 percent of the value of Canada's metallic mineral production. Canada ranks first in the world as a producer of zinc, third in silver, molybdenum and gold, and fourth in copper and lead.[15]

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[14] For further information on the data base outlined here, see B.W. Mackenzie, Economic Mineral Exploration Targets, Working Paper No. 28, Centre for Resource Studies, Kingston, January 1984, 63 pp.

Base metal mining is an interesting subject for the examination of resource quality and productivity effects. Canada's base metal endowment has been intensively and extensively explored. However, undiscovered base metal deposits are masked by a relatively complex set of geological conditions. The base metal sector is topical, being central to both the post-1982 mining recession and the sunset industry notion.

Study Specifications

The case study concerns 275 significant base metal deposits discovered in Canada to 1977, classified by discovery date. In the final stage of analysis, these discoveries are grouped into three main geological categories, volcanic-associated, sediment-hosted, and porphyry deposits, to provide a more consistent basis for comparison.

The effect of resource quality on mining productivity is examined by considering time trends in the number of economic deposits discovered, and the geological and economic characteristics of those discoveries. Thus, the 65 significant deposits discovered prior to 1946 are distinguished from the 210 discoveries made during the modern era of base metal exploration, the 32-year period 1946-77. The 1946-77 period is subdivided into four 8-year intervals for analysis purposes.[16]

All money values are expressed in constant 1983 dollars. The gross national expenditure implicit price index is used to inflate historical data to 1983-dollar equivalents.

In order to asses the effect of resource quality on productivity, each historical discovery is evaluated on the

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15. Traditionally, about 20 percent of Canada's copper production is a byproduct of nickel mining. Approximately 95 percent of its silver production and 30 percent of its gold production have been derived as byproducts from base metal mining.
16. While the selected time intervals are somewhat arbitrary, they are intended to provide a balance between the need for a sufficient number of intervals to detect time changes, and the requirement for a sufficient sample size of discoveries within each interval.

basis of a standard set of current economic and technological outlook conditions. An economic deposit is defined as a discovery which realizes a total revenue of at least $20 million and a rate of return of at least 8 percent. The $20 million minimum size insures that any deposit of significance is included in the evaluation. The 8-percent rate-of-return investment margin has been selected as our best estimate of the weighted average cost of capital for mineral investment funds.[17]

Possible Economic Discoveries for Evaluation

A total of 275 discoveries which could possibly satisfy economic deposit conditions are selected for evaluation.[18] The distribution of these possible economic discoveries among time intervals is presented in table 2.

The intention is to include all known base metal deposits which offer medium-term potential for development. Deposits are classified by discovery date. A discovery is considered to be made when the deposit which ultimately forms the basis for mine development is first encountered by drilling. Deposits are treated individually if their discovery required essentially independent primary exploration programs.

Of the total number of deposits, 210 were discovered during the 32-year period 1946-77. There appears to have been a significant increase in discovery rate until the mid-1960s, followed by a modest decline.

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[17] The weighted average cost of capital in constant money terms is comprised of the costs of individual sources of funds. Sources of funds may be simply grouped into two types - debt and equity. Considering inflation and taxation effects, debt capital represents a low cost source of funds, with constant money after-tax costs normally in the range of 1 to 3 percent. The cost of equity funds typically varies from 6 to 15 percent. The financial structure of a mining company - basically how much debt and how much equity it utilizes - is then applied to cost estimates for the individual sources to assess the weighted average cost of capital. The 8-percent weighted average cost of capital assumed in this study should be viewed within this framework.

[18] A listing of these deposits, classified by discovery date is given in appendix II, Economic Mineral Exploration Targets, pp. 51-54.

Table 2

POSSIBLE ECONOMIC DISCOVERIES FOR EVALUATION

Total	275
By time interval:	
Pre-1946	65
1946-53	41
1954-61	49
1962-69	66
1970-77	54

General Market Estimates

General market estimates are made to evaluate the time distribution of revenues for each of the possible economic discoveries.

Metal price is both the most important and the most uncertain variable in the assessment of cash flows. The expected long-term price projections used are shown in table 3. These are intended to reflect current outlook conditions.

Table 3

LONG TERM METAL PRICES
(U.S. dollars)

Metal	Price Basis	Expected Price
Copper	per pound metal	1.05
Gold	per ounce metal	550
Lead	per pound metal	.35
Molybdenum	per pound in con.	6.00
Silver	per ounce metal	13
Zinc	per pound metal	.60
Exchange Rate	U.S.$ per C$	.80

These estimates are long-term average price projections, the period of which is intended to correspond to the productive life of the deposits being evaluated, typically 6-20 years starting 2-3 years from now. The price estimates presented in table 3 and used in the study may be considered optimistic in terms of present price levels and in terms of current market projections which tend to be correlated with the recent past. However, it should be realised that current market prices are spot, not average, prices. Furthermore, present prices for most of the base metals represent all-time record lows in constant money terms. Because of the high degree of short-term cyclicity which characterizes base and precious metal markets, the statistical relationship between spot prices, such as those currently prevailing, and long-term average price projections, such as those adopted in this study, is in fact slight.

The assessment of costs and revenues assumes that metal concentrate is produced at each possible mine. General net smelter return conditions for copper, lead and zinc concentrates are used to convert the forecast metal prices to revenue estimates for the sale of concentrates at the smelter.[19] Concentrate transportation charges are then deducted to work the smelter payment back to a minesite value.

Individual Deposit Estimates

Individual deposit-by-deposit estimates of recoverable ore reserves, ore capacity, preproduction period, preproduction capital cost, the cost of major modifications, sustaining capital, operating cost, metallurgical recoveries, concentrate grades, and concentrate transportation, have been calculated for each of the possible economic discoveries, based on present-day economic and technological conditions. These deposit estimates utilize actual historical data and feasibility study estimates to the extent available. Otherwise, generalized Canadian costing relationships are applied, reflecting an order-of-magnitude level of accuracy.[20]

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[19] The net smelter conditions for copper, lead and zinc concentrates are based on the worldwide survey and analysis of approximately 200 actual smelter contracts by Lewis and Streets. See: P.J. Lewis and C.G. Streets, 'An Analysis of Base-Metal Smelter Terms', in the Proceedings of the Eleventh Commonwealth Mining and Metallurgical Congress, Hong Kong, 1978, Institution of Mining and Metallurgy, London. A number of modifications have been made based on discussions with marketing personnel to adapt their general results to more specific Canadian conditions.

With respect to processing facilities, where more than one deposit of the same type exists in a region, deposits are evaluated assuming utilization of a common mill facility. The overall regional mill capacity is specified, as is the distance between the deposit and the mill. The deposit is allocated a proportion of the mill capital cost based on relative capacities. The distance is used to estimate a road-haulage transportation cost for the ore. Additional road construction may be specified.

Actual deposit data and feasibility study estimates have mainly been obtained directly from the mining companies concerned. General sources of deposit information include Energy, Mines and Resources Canada mineral inventory cards, the Financial Post Corporation Service, the Northern Miner library, and published reports and papers.

Data Base Critique

The completeness and reliability of individual deposit data is a function of discovery date; i.e., the data base for older mines is more comprehensive than that available for more recent discoveries. This distinction is especially important with respect to ore reserve estimates, since development and production typically proceed on the basis of partial delineation results. The intention is to include as complete an estimate as possible for the tonnage of each deposit. Nevertheless, there is a tendency to undervalue productive mine lives and positive cash flows, particularly for deposits discovered most recently. This problem can be eased by periodic updating and improvement of the data base.

This and other shortcomings in the data base reflect a compromise between the availability of data and the research limitations imposed by time constraints. There is much room for improvement. However, the margin of error which may exist in the analysis is not thought to be large enough to invalidate the overall results and conclusions.

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[20] For an outline of these generalized deposit costing relationships, see appendix II, pp. 29-30 in B.W. Mackenzie and M.L. Bilodeau, Economic Guidelines for Small Mineral Deposits: Directives economiques relatives aux petits gisements, Working Paper No. 25, Centre for Resource Studies, Kingston, April 1982, 66 pp.

The Quality of Base Metal Resources

Base Case Conditions

The base case conditions, which are used as a standard of comparison with other results, are:

- all possible economic deposits discovered in Canada during the period 1946-77;
- expected metal price conditions;
- $20-million minimum acceptable total revenue for an economic deposit;
- 8-percent minimum acceptable rate of return for an economic deposit.

Under these conditions, 96 of the 210 base metal deposits are found to be economic. The cost and revenue characteristics of the 96 deposits are averaged to determine the time distribution of average cash flows for an economic deposit. The various productivity measures previously outlined are derived from these development- and production-phase cash flow estimates.

The expected return from development and production for an economic deposit is found to be $272 million, expressed as a discounted value at the start of development. This is equivalent to a potential or before-tax rate of return of about 34 percent. The expected or average size of an economic deposit is estimated to be 54 million tonnes of ore. Zinc accounts for 51 percent of the value of these deposits, copper for 24 percent, silver for 10 percent, lead for 9 percent, and gold and molybdenum for 3 percent each.

With regard to the expected cash flow components for an economic deposit, the gross in-situ value, reflecting geological grade, is $193 per tonne. Mining losses represent $24 per tonne, milling losses $29, smelting and refining charges $46, and concentrate transportation costs $9 per tonne of ore. Thus, the revenue at the minesite is $85 per tonne ($193 - 24 - 29 - 46 - 9 = $85 per tonne). Pre-production capital costs represent $12 per tonne, and production costs $35 per tonne. Thus, the potential or before-tax cash flow is $38 per tonne of ore ($85 - 12 - 35 = $38 per tonne).

Time Trends

The 65 significant base metal deposits discovered before 1946 are included here to provide a more complete picture of the changing quality of resources. Results for the 1946-77 period are disaggregated into the four 8-year time intervals. All other conditions are assumed to be the same as in the base case.

Productivity results are summarized in tables 4 and 5. Significant findings are:

- economic discoveries made before 1946 are found to be significantly more profitable on average than those discovered during the 1946-77 period. The effects of the preeminent Sullivan, Flin Flon, and Horne deposits on the average results for this pioneering era are no doubt substantial;

- the proportion of precious metals byproducts is much higher for the pre-1946 period, indicating the discovery of a relatively large share of polymetallic volcanic-associated ores;

- expected return and rate of return characteristics of economic discoveries deteriorate from 1946-53 to 1954-61, improve for the 1962-69 interval, and then fall off once again for the most recent 1970-77 interval. No systematic overall time trend is apparent;

- the serious decline in return characteristics for the 1954-61 interval, symptomatic of depletion effects, may be a result of the more intensive application of an exploration technology that was essentially unchanged from that of the 1946-53 interval to lower priority targets;

- the influence of large low-grade economic porphyry deposits is shown to be mainly concentrated in the interval 1962-69. This is illustrated by the high expected return and average deposit size for the interval, as well as by the relatively large proportions of copper and molybdenum in the product mix. The high expected rate of return for 1962-69 appears to contradict the notion that porphyry deposits are not generally very profitable. However, other high-grade and more profitable discoveries are likely influential here, such as the Kidd Creek discovery in 1964 and the Ruttan deposit discovered in 1969;

Table 4

TIME TRENDS IN THE EXPECTED RETURN CHARACTERISTICS FOR AN ECONOMIC DEPOSIT

	Discovery Date				
	Pre-1946	1946-53	1954-61	1962-69	1970-77
Number of economic deposits	17	16	26	27	27
Return ($ million)	564	272	109	485	214
Rate of return (percent)	59	38	25	41	28
Deposit size (t million)	21	18	16	131	34
Product mix: (percent)					
Zinc	37	60	44	32	70
Copper	17	11	29	44	7
Silver	14	17	11	10	5
Lead	14	11	5	3	16
Gold	18	1	11	3	2
Molybdenum	-	-	-	8	-

- the greater proportions of zinc and lead in the metal mix for economic deposits discovered during 1970-77 points to the increased importance of sedimentary-hosted deposits. This trend may also explain the large average size of these most recent discoveries, second only to that of deposits discovered in the 1962-69 interval;

- time series results for gross in-situ value per tonne indicate that there has been no methodical falling off in average ore grades. The decrease in grade shown for 1954-61 and, particularly for the 1962-69 interval, reflect the influence of the economic porphyry deposits. The average ore grade for the most recent inter-

Table 5

TIME TRENDS IN THE EXPECTED CASH FLOW COMPONENTS FOR AN ECONOMIC DEPOSIT
($ per tonne of ore)

	Discovery Date				
	Pre-1946	1946-53	1954-61	1962-69	1970-77
Gross in-situ value	240	228	191	146	223
Mining losses	36	30	29	15	27
Milling losses	37	34	29	19	36
Treatment charges	46	56	42	37	54
Transportation costs	6	9	6	8	12
Revenue at the minesite	115	99	85	67	94
Capital expenditures	13	11	13	10	13
Production costs	38	39	34	25	41
Before-tax cash flow	64	49	38	32	40

val (1970-77) is essentially the same as at the start of the series;

- the poorer average grades of the economic deposits discovered in 1954-61 and 1962-69 are partially compensated for by lower unit mining and milling losses, reduced treatment charges, and lower unit capital expenditures and production costs. Thus, the before-tax cash flow per tonne of ore for these two intervals does not decline as markedly;
- the generally increasing trend in concentrate transportation costs reflects the increasing remoteness of economic deposits relative to established smelting and refining facilities;

- differential time value effects for high-grade and low-grade deposits explain apparent inconsistencies between the discounted return values in table 4 and the undiscounted unit cash flows in table 5. For example, the discrepancy between the relatively low before-tax cash flow per tonne and the high expected rate of return for an economic deposit during the 1962-69 interval is caused by the large proportion of high-grade ores in the early production years of the time distribution of average cash flows.

Summary

No systematic trend is apparent in the quality of base metal resources discovered during the 1946-77 period. If economic deposits discovered prior to 1946 are included in this examination, a decline in the expected return and rate of return productivity indicators may be discerned. In view of the long time-frame considered, any falling off in the average return characteristics of economic deposits and, hence, any decline in the productivity of Canada's base metal resources, is much more gradual than is generally believed.

The findings presented here show a high degree of variability in results among the individual time intervals. These fluctuations are of course what make it so difficult to detect long-term productivity trends. Such variations are partly a result of the high-risk random element inherent in the mineral exploration and discovery process. Also, as the foregoing explanations suggest, the fluctuations are also caused by the diverse qualities and changing mixture of geological deposit types. To remove this second influence, time trends in the quality of base metal resources are now examined by grouping discoveries into more geologically consistent categories.

Classification of Base Metal Resources by Deposit Type

Mineral deposit types reflect specific geological settings. Exploration is directed towards those types of deposit which are perceived to be most economically attractive.

In order to obtain a more geologically consistent view of the changing quality of resources, base metal deposits are classified here into three main types: volcanic-associated massive sulphide, sedimentary-hosted massive sulphide, and porphyry deposits.[21]

Tables 13 and 14 compare productivity indicators for all economic deposits found to 1977, classified by deposit type. The expected return from development and production, expressed as a discounted value at the start of development, is shown to be remarkably similar among the three deposit types considered, varying from $163 million for the economic volcanic-associated deposits to $212 million for the sedimentary-hosted deposits. Further examination shows that this similarity is due to the cancelling out of strikingly different size, grade and profitability characteristics.

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[21] Volcanic-associated massive sulphide deposits are defined by three major characteristics: occurrence of mineralization in a stratiform zone of massive sulphides; association of deposits with extrusive submarine volcanic rocks; and deposition of the ore from the discharge waters of submarine hot springs. Volcanic-associated deposits are typically small and high grade. Occurring in active tectonic zones at intervals through the entire geological time frame, volcanic-associated deposits are found in the shield, appalachian, and cordilleran environments.

Sedimentary-hosted massive sulphide deposits are defined on the basis of their association with sedimentary host rocks, typically shale or carbonate marine sediments. Sedimentary-hosted zinc-lead deposits, which may contain copper and silver, are usually of medium size and grade, occurring in sediments formed since about 2,000 million years ago. This deposit type is mainly found in the appalachian and cordilleran environments.

Porphyry deposits are invariably related, both spatially and genetically, to highly fractured and hydrothermally altered zones in complex high level felsic intrusions within active tectonic belts. Porphyry deposits are typically large and low grade, and may contain copper only, copper-gold, copper-molybdenum, or molybdenum with or without tungsten. This deposit type tends to be identified with relatively young rocks, especially mesozoic-tertiary active zones such as the cordilleran environment.

Table 6

EXPECTED RETURN CHARACTERISTICS FOR AN ECONOMIC DEPOSIT BY TYPE

	Volcanic-Associated Deposits	Sedimentary-Hosted Deposits	Porphyry Deposits
Number of economic deposits	63	24	11
Return ($ million)	163	212	177
Rate of return (percent)	53	42	23
Deposit size (t million)	16	44	298
Product mix (percent):			
Zinc	47	72	-
Copper	25	-	69
Silver	15	7	4
Lead	4	21	-
Gold	9	-	7
Molybdenum	-	-	20

Sixty-three of the 152 volcanic-associated massive sulphide discoveries recorded to 1977 have been evaluated as economic, including the Brunswick deposits, Buchans, Corbet, Flin Flon, Fox, Geco, Goldstream, Horne, Kidd Creek, Lynx, Mattagami, Norbec, Normetal, Quemont, Ruttan, Selbaie, and Sturgeon. Economic deposits of this type are characteristically small and high grade, as shown by the average deposit size and gross in-situ value per tonne indicators in tables 6 and 7, although a select few are large. Zinc and copper are generally the most important constituent metals, but appreciable precious metals are often present as well, averaging almost one-quarter of the total product value. Volcanic-associated deposits, once found and delineated, tend to be very profitable, the potential rate of return for an economic discovery averaging 53-percent for the assumed conditions.

Twenty-four of the 37 sedimentary-hosted massive sulphide deposits found to 1977 satisfy economic deposit conditions, including Faro, HB, Howards Pass, Nanisivik,

Table 7

EXPECTED CASH FLOW COMPONENTS FOR AN ECONOMIC DEPOSIT BY TYPE
($ per tonne of ore)

	Volcanic-Associated Deposits	Sedimentary-Hosted Deposits	Porphyry Deposits
Gross in-situ value	254	192	29
Mining losses	35	19	1
Milling losses	41	26	4
Treatment charges	55	60	4
Transportation costs	9	13	1
Revenue at the minesite	114	74	19
Capital expenditures	15	9	2
Production costs	43	29	8
Before-tax cash flow	56	36	9

Newfoundland Zinc, the Pine Point complex of deposits, Polaris, and Sullivan. These deposits, which yield mainly zinc and lead with a minor silver byproduct, are usually of medium size and medium-high grade, although, once again, the occasional discovery such as Howards Pass and Sullivan is large. Economic sedimentary-hosted deposits, somewhat less profitable than the volcanic-associated ores, nevertheless typically offer handsome before-tax rates of return, averaging 42 percent.

The 11 economic porphyry deposits, evaluated from a total of 30 significant discoveries recorded, are characterized by their very large size and very low grades. These economic discoveries include Afton, Bell, Bethlehem, Brenda, Endako, Highmont, Island Copper, and Lornex. While copper and molybdenum predominate in the product mix, there also may be an appreciable precious metal content, shown in table 6 to average more than one-tenth of the overall product value. These deposits are typically much less profitable than the economic volcanic-associated and sedimentary-hosted discoveries, the rate of return from development and production averaging 23 percent.

Thus, base metal deposits classified by type have distinctive geological and economic characteristics. It is not difficult to surmise that a changing mixture of deposit types would have a notable influence on the overall time trend results considered in the previous section. How has the role of these deposit types changed with time, and what factors explain the changes which have taken place?

The Changing Mixture of Deposit Types

The selection of deposit types as exploration targets is based on highly uncertain judgments which vary with time. Changing emphasis in target selection and, therefore, in the allocation of exploration funds, ultimately results in changing proportions of actual discoveries among the base metal deposit types.

The following examples illustrate some of the factors which have influenced the relative importance of base metal deposit types in Canada. The advent of airborne geophysical techniques in the late 1940s and early 1950s stimulated the exploration and discovery of volcanic-associated massive sulphide deposits. A strong shift towards porphyry deposits in the 1960s was associated with buoyant copper and molybdenum market conditions (particularly concentrate markets in Japan), government tax incentives, and advances in the development of large-scale open pit and mineral processing technology. The relative importance of sedimentary-hosted deposits in the 1970s has been influenced by improved conceptual geological models and relatively strong zinc markets. A more recent swing back to volcanic-associated exploration targets has been encouraged by the more-modest investment requirements and lower risk associated with the development of small high-grade mines, the market hedge provided by the polymetallic nature of the volcanic-associated ores, and high gold and silver prices.

Time Trends by Deposit Type

While the changes in perception which influence the allocation of exploration funds among deposit types include geological factors, there is obviously a much broader range of technological and economic factors at work. In order to reveal what is happening beneath these diverse changes, time trends are more specifically examined here for volcanic-associated deposits, and for a somewhat restricted sedimentary-hosted deposit time series. Economic porphyry deposits, too few in number and too concentrated by discovery date for time series analysis, are isolated by their exclusion. These deposit type assessments allow us to examine more consistently the changing quality of base metal resources and its effect on mining productivity.

Volcanic-Associated Massive Sulphide Deposits

There have been a sufficient number of economic volcanic-associated massive sulphide deposits discovered throughout the timeframe of interest to retain the intervals used for the overall time trend assessments. The productivity indicators are presented in tables 8 and 9.

Table 8

TIME TRENDS IN THE EXPECTED RETURN CHARACTERISTICS FOR AN ECONOMIC DEPOSIT: VOLCANIC-ASSOCIATED DEPOSITS

	Discovery Date				
	Pre-1946	1946-53	1954-61	1962-69	1970-77
Number of economic deposits	13	10	17	9	14
Return ($ million)	208	195	71	405	55
Rate of return (percent)	60	42	30	80	31
Deposit size (t million)	14	24	11	33	8
Product mix (percent):					
Zinc	26	60	53	47	46
Copper	29	11	18	35	28
Silver	9	18	14	16	19
Lead	2	10	6	1	2
Gold	34	1	9	1	5
Molybdenum	-	-	-	-	-

Table 9

TIME TRENDS IN THE EXPECTED CASH FLOW COMPONENTS FOR AN ECONOMIC DEPOSIT: VOLCANIC-ASSOCIATED DEPOSITS ($ per tonne of ore)

	Discovery Date				
	Pre-1946	1946-53	1954-61	1962-69	1970-77
Gross in-situ value	272	275	227	246	260
Mining losses	42	37	31	36	32
Milling losses	45	43	38	35	44
Treatment charges	51	65	52	56	54
Transportation costs	6	11	8	9	11
Revenue at the minesite	128	119	98	110	119
Capital expenditures	15	12	13	17	18
Production costs	41	46	38	42	51
Before-tax cash flow	72	61	47	51	50

Time series results for this more specific grouping of base metal deposits are indeed found to be more systematic than those presented in the previous section for all deposits. However, there are still notable fluctuations, reflecting the random aspect of exploration in terms of the varying quality of mineral deposits discovered. In particular, the presence of the Kidd Creek deposit, the best base metal deposit found in Canada to date, has a pronounced effect on the expected return characteristics for the 1962-69 interval as one of only nine economic deposits included. Interestingly, this discovery does not have the same observable effects on the unit cash flow characteristics.

With regard to ore grades, there is little if any evidence of depletion effects. Average grades fall off somewhat to 1954-61 but have increased since then, approaching their pre-1946 level in the 1970-77 interval. Hence, the ore grades of volcanic-associated deposits have not been declining.

Modest overall increases in unit costs may be discerned from table 9. These presumably reflect a falling off in the quality of base metal resources in terms of increasing remoteness and depth. It is surprising that the associated cost increases are not more significant.

As a consequence of the grade and cost trends the before-tax cash flow of economic volcanic-associated deposits per tonne of ore declines to 1954-61, remaining essentially unchanged thereafter.

The very high gold content for the economic deposits discovered prior to 1946 is likely related to the early prospecting methods employed. Prospectors, primarily looking for gold, discovered gold-rich base metal deposits by panning stream sediments, systematically working their way to the source.

There are significant changes in the expected return and expected rate of return productivity indicators, reflecting the combined effects of unit cash flow values, deposit size, and time value. In particular, there is a notable deterioration in these indicators until 1954-61. However, results for the 1962-69 interval, influenced by the Kidd Creek discovery, represent all-time highs.

Overall economic results for the most recent 1970-77 interval are disappointing. One possible explanation is depletion effects in terms of smaller, less profitable economic discoveries. On the other hand, an inherent bias in the data base that results in undervaluation of the more recent discoveries has been acknowledged. This bias is strongest with respect to ore reserve tonnage or, in other words, average deposit size. Furthermore, this bias is no doubt particularly pronounced for volcanic-associated deposits, which are the most erratic and difficult to delineate of the three types considered. Thus, when the data base is updated in the course of time, it would be surprising if the 8-million tonne average deposit size estimated for the 1970-77 interval did not increase significantly. This would, in turn, enhance the expected return and rate of return characteristics.

Volcanic-associated massive sulphide deposits in Canada represent the longest-standing, most intensively pursued type of exploration target, and one of the most mature exploration environments worldwide. This point is illustrated by the fact that the environment yielded 152 significant discoveries to 1977. Hence, it may be surmised that the exhaustion of discovery possibilities for this deposit type, and consequent depletion effects, are relatively advanced.

Nevertheless, little evidence can be found in the productivity results presented here to support the contention that the quality of volcanic-associated ores is declining.

Sedimentary-Hosted Deposits

The number of economic sedimentary-hosted massive sulphide deposits and their time distribution are insufficient to enable assessments to be made for all time intervals. Only one of the pre-1946 discoveries (Sullivan) satisfies economic deposit conditions; also, there is only one economic discovery in the 1954-61 interval. Thus, the results presented in tables 10 and 11 are grouped for a 16-year interval, 1946-61, followed by the intervals 1962-69 and 1970-77. For comparative purposes, productivity indicators for all economic sedimentary-hosted deposits are also shown.

Table 10

TIME TRENDS IN THE EXPECTED RETURN CHARACTERISTICS FOR AN ECONOMIC DEPOSIT: SEDIMENTARY-HOSTED DEPOSITS

	Discovery Date			
	1946-61	1962-69	1970-77	Total
Number of economic deposits	5	7	11	24
Return ($ million)	49	138	171	212
Rate of return (percent)	28	43	27	42
Deposit size (t million)	7	21	65	44
Product mix (percent):				
Zinc	79	73	78	72
Copper	-	-	-	-
Silver	7	6	3	7
Lead	14	20	19	21
Gold	-	1	-	-
Molybdenum	-	-	-	-

Table 11

TIME TRENDS IN THE EXPECTED CASH FLOW COMPONENTS FOR AN ECONOMIC DEPOSIT: SEDIMENTARY-HOSTED DEPOSITS
($ per tonne of ore)

	Discovery Date			
	1946-61	1962-69	1970-77	Total
Gross in-situ value	188	170	205	192
Mining losses	24	5	24	19
Milling losses	21	21	31	26
Treatment charges	58	61	61	60
Transportation costs	10	14	15	13
Revenue at the minesite	75	69	74	74
Capital expenditures	10	10	9	9
Production costs	27	25	34	29
Before-tax cash flow	38	34	31	36

The following significant points may be noted from the results presented:

- these more geologically-consistent indicators of productivity change are more systematic than for all deposit types mixed together;

- the economic discovery rate increases over the study period;

- a marked increased in the average size of economic deposits is apparent, influenced in part by the inclusion of the very large Howards Pass discovery in the most-recent 1970-77 time interval;

- the metal product mix remains remarkably uniform. There is much less variability in this respect among sedimentary-hosted ores than among the volcanic-associated deposits;

- ore grades have not declined with time. The gross in-situ value per tonne of ore in the most recent interval is in fact found to be somewhat higher than the average for all economic sedimentary-hosted deposits;

- a modest increase in both unit losses and unit costs may be observed in table 11, reflecting the consequences of increasing remoteness, depth, and mineralogical complexity on the productivity of sedimentary-hosted base metal resources;
- a modest decline in before-tax cash flow per tonne of ore is indicated, resulting from the observed grade and unit cost trends;
- the high productivity of all sedimentary-hosted base metal resources taken together relative to results for the individual time intervals reflects the superior endowment characteristics of the initial pre-1946 discovery, the Sullivan deposit. This is one instance where the highest quality deposit appears to have been discovered first;
- a significant increase in the expected return for an economic sedimentary-hosted discovery from 1946-61 to 1970-77 is shown in table 10, mirroring the time trend in average deposit size;
- a rise from 1946-61 to 1962-69, followed by a fall from 1962-69 to 1970-77 in the expected rate of return for the development and production phases.

The assessments presented here do not support the belief that the quality of sedimentary-hosted massive sulphide deposits is declining.

Summary

A changing mixture of deposit types is associated with the historical time pattern of base metal discoveries in Canada. These fluctuations and trends can only be explained by a complex and uncertain set of actual and perceived economic conditions pertaining to base metal supply. This suggests that time trends in the quality of base metal resources and the consequent effects on mining productivity may be most validly examined for specific deposit types.

The evidence presented in this section is incomplete. Time series analysis is possible only for the volcanic-associated and sedimentary-hosted deposit types. However, it is notable that the evidence which is available does not support the contention that the quality of Canada's base metal resources has deteriorated with time.

Conclusions

An evaluation procedure has been developed for examining the effect of the quality of mineral resources on productivity change in the mining sector. The application of this approach is intended to contribute to the continuing dialogue on the role of mining in the Canadian economy.

The case study results presented for base metal resources should be regarded as illustrative. A more comprehensive study of the productivity of Canada's mineral resources would be required to support more definitive statements, including:

- analysis of the sensitivity of changes in the productivity of base metal resources observed here to variations in key parameters such as long-term metal prices;
- more complete assessment of the effects of all geological factors on the productivity of base metal resources, considering time trends in exploration expenditures as well as changes in the quality of the resulting discoveries;
- application of the methodology to other mineral resources of importance to Canada, such as nickel, iron ore, asbestos, potash, coal, and gold.

This further research should be assigned a high priority because an understanding of the trends in Canadian mining productivity is critical to the rational formulation of both economic development strategy and mineral policy.

Despite the limitations of the case study examined here, a large number of base metal deposits discovered over an extensive historical period are considered. Although some of the results may be subject to differing interpretations, the evidence presented does not in general support the hypothesis that the quality of Canada's base metal resources is declining. Certainly ore grades, within consistent deposit-type groupings, have been maintained. Any modest deterioration in the productivity of base metal resources otherwise observed must be weighed against the bias inherent in the data base to undervalue more recent discoveries.

If this uncertain finding is in fact valid, why has the quality of base metal resources been maintained? Two main reasons are suggested. First, base metal exploration, despite much scientific study and practical experience, is a very complex process which is still only poorly understood. The exploration process is not nearly as systematic as some would believe, and certainly does not proceed methodically from high quality to low quality discoveries. Thus, it appears that depletion, in the guise of declining resource quality, manifests itself quite slowly and may have serious national consequences only over a timeframe even longer than the one considered here. Scientifically-based exploration is no doubt better than purely random exploration, but perhaps not by much.

Second, the positive productivity effects of advances in geological concepts and exploration technology, possibly because they have not been fully documented and cannot be readily measured, tend to be undervalued. The results presented here for Canada's base metal resources suggest that these scientific improvements have been sufficient to offset the negative depletion forces. Consequently, resource quality does not appear to be declining.

Study findings call into question not only the widely held belief that the quality of Canada's mineral resources is declining, but also the negative overall trends evaluated in mining productivity studies. If the quality of the mineral resource input is not declining it is hard to imagine, in light of mining and processing advances introduced during the study period but not accounted for here, that there has not been a positive rate of improvement in overall mining productivity.

Study results in no way deny that the current problems in Canada's base metal sector are severe. Rather, the findings suggest that if base metal resources gave Canada a competitive advantage in international markets historically and, in so doing, played a key role in national economic development and prosperity, there is reason to believe that they can continue to do so well into the future.

Current problems in the base metal sector are not inherent in our mineral endowment. Canada's high-quality resource base is still essentially intact. The challenge is to shape its development to best suit the changes emerging in long-term international market conditions.

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PART II

CORPORATE AND GOVERNMENT POLICY ENVIRONMENT

GOVERNMENT INITIATIVES RELATING TO PRODUCTIVITY INCENTIVES

C. George Miller

The topic of this seminar - Mining Productivity - is certainly timely. The Mineral Policy Sector of EMR has been looking closely at the future prospects of Canada's mining industry. We have concluded that, for many reasons, the Canadian minerals industry is to face increasingly stiff competition for mineral sales in international markets. Our miners will be competing for sales with producers from countries where wage rates are lower, where environmental costs are minimal or nonexistent, where government subsidies are available, and in some cases, where high-quality deposits exist. Therefore, if we are to maintain, let alone increase, our share of world markets, we will have to remain cost competitive with producers enjoying such advantages, and increasing productivity is one of the few ways in which we can offset these.

I was asked to speak about government initiatives relating to productivity incentives. Clearly, this is only one aspect of the complex problem of improving productivity. Other speakers are looking at some of the other aspects, many of which lie primarily in the realm of private-sector decisions, such as labour-management relations. One striking example of the potential for productivity increases through improved employer-employee relations was reported in the February 1984 issue of Canadian Business. Ford of Canada encouraged its workers to participate in production decisions, resulting in lower costs and higher quality. It is worth noting, however, that in a broad sense, governments - federal, provincial and municipal - set the ground rules under which both business and labour operate in Canada. If we conclude, as I suspect we may, that an improvement in labour-management relations would contribute generally to higher productivity, then governments may have a role in promoting such an improvement.

Another major factor in productivity improvement, as we have seen in recent months, is the ability of private-sector managers to focus on a strategy of strict cost control when the survival of the firm is threatened. Not only are 'frills' cut out, but also expenditures are eliminated which are normally judged important to the long-term prosperity of the organization (such as technical support, maintenance, ore development, and research). More significantly, losing operations are shut completely and employment is drastically reduced at those which continue to operate. The human cost of such periodic adjustments is very substantial, and they can lead to both individual and community distress for those affected. Nevertheless, the net effect, for at least a period of time, is to dramatically improve the cost-competitiveness of our operating mines in the short term.

Government policies and programs which apply to this situation (such as unemployment insurance and related programs) are intended to ease the necessary transitions and to cushion the impacts on individuals, while allowing economic adjustments to occur in response to market forces. The degree to which existing programs meet these criteria could well be a useful subject of discussion at this seminar. However, this is an area that I will not explore further at this time.

Government Initiatives for Systematic Productivity Improvement

I have just mentioned several private-sector approaches to productivity improvement in the interests of corporate survival. By contrast, I would like to focus my remaining remarks on several ways in which government initiatives can promote systematic increases in productivity. In general we know that productivity can be improved by innovation, or the implantation of technology at the workplace. Technology may be conventional, or it may be new.

Dr. Whitham, later in the seminar, will be discussing ways in which the technical activities of government may be coordinated with, and may reinforce, the efforts of industry to develop and introduce new technology. I will therefore touch only lightly on these, and instead concentrate on how the other policy instruments of government may be used to promote the development and installation of technology by the private sector. Research and development are costly, and even when the technology is available, considerable capital investment is usually required to install it in a new or existing mine or plant. Therefore, any initiative by government that can selectively reduce the financial burden of these innovations and investments may be considered a 'productivity incentive'.

Governments already have a wide range of programs designed to do this. Most of them are of general application, but a few are applicable specifically to the mining sector. These programs vary, but include such things as:

- financial assistance provided through the tax system;
- the provision of data, research findings and the like, by governments;
- policy support;
- direct financial aid, to specific companies or individuals, in the form of grants or loans for specific purposes.

Both federal and provincial governments, of course, have such programs.

Tax Incentives

At the federal level, the most obvious and probably most important such incentive is the support offered to productivity-related research and development (R and D) projects through the tax system. Under present legislation three types of tax incentives are available.

First, an immediate deduction may be made by an R and D performer, in computing taxable income, of 100 percent of defined current expenses and capital expenditures related to R and D. This benefit is available to individuals and corporations and has a very high present value for those who pay taxes at a high rate.

Secondly, investment credits may be earned and offset against federal income tax for current and capital R and D expenditures. These tax credits have been in place since 1977 and they vary with the year in which expenditures were incurred and with the location and type of R and D performer. The April 1983 federal budget eliminated the 50 percent additional allowance and replaced it with increased R and D tax credits as follows:

	Previous Rate	Present Rate
General rate for large corporations and individuals	10%	20%
Large corporations and individuals in Atlantic Canada and the Gaspé	20%	30%
Rate for small business corporations	25%	35%

Thirdly, the April 1983 budget introduced special measures to assist the financing of R and D by performers who faced some limit on their ability to use the above tax incentives. (Approximately 70 percent of R and D is performed by firms in this category.) The measures provide that an R and D performer (corporation only) may renounce its rights to R and D tax deductions and effectively flow out the benefits in the form of a tax credit to investors in the corporation. Investors who buy shares, debt instruments or R and D royalty contracts of the corporation are entitled to a 50-percent Scientific Research Tax Credit (SRTC) where the proceeds are designated to be used for R and D. The R and D financing provisions provide immediate and substantial tax benefits to investors and provide the corporation with considerable flexibility in setting up financing alternatives. They have already proven to be very popular with both the R and D and investment communities.

These tax deductions, of course, are available to all sectors. However, there is a particular difficulty which we should note in their application to mining. A great deal of applied research takes place in producing mines. Many - probably most - of our mines do such things as experimenting with modified equipment, testing new mining methods, improving safety procedures, and the like. It is very difficult for them to segregate the costs and revenues associated with this research and development work from those of their normal production. Perhaps for that reason, mining research done in relation to mineral production seems to be prevented from claiming certain tax benefits. This whole matter has been the subject of representations from some members of the industry. Perhaps the current seminar will present an opportunity to develop and recommend a suitable initiative.

Most of the provinces offer tax deductions for research and development costs similar to those I have described. The situation differs in various provinces.

Provision of Scientific and Technical Findings

The federal government, and most provincial governments, carry out a wide range of research, both basic and applied, both in the field and in goverment laboratories and related institutions. Governments also finance research in universities through agencies such as the Natural Sciences and Engineering Research Council. In general, the results of this technical work and research are made available for the use of Canadian industry, thus providing a major incentive in kind for enhanced productivity.

In the minerals field, obvious examples are the work of the federal and provincial geological surveys. These organizations have, over the years, made an immense volume of geoscience data available, and continue to do so. This enables our mineral exploration industry to focus its efforts in the relatively small areas where the likelihood of finding commercially viable mineral deposits is greatest, thus enhancing the productivity of this sector of the industry immensely.

The Geological Survey has also pioneered in the development of new geophysical and geochemical methods for locating concealed mineral deposits, and in the practical application of these methods under Canadian exploration conditions. This work has contributed significantly to the growth of the geophysical and geochemical surveying industries, fields in which Canadian companies are acknowledged to be among the world leaders. The most recent example is the development, testing, and licensing to industry of the airborne gradiometer.

Similarly, CANMET has worked closely with the industry in the fields of mining technology development, metallurgical research, and related subjects, again providing a major productivity enhancement for the mining and processing sectors of the industry. My colleague, Dr. Whitham, will have more to say about this subject later in the program.

Policy Support

My own organization, the Mineral Policy Sector of EMR, works closely with other federal departments and with mineral policy groups in the provinces and territories towards the objective of providing as far as possible a policy environment in which the mining industry can make its maximum contribution to the economic well-being of our country. To the extent that these efforts are successful, we like to think that we are also making a contribution to the industry's productivity. Our policy advisory role extends to all areas of government action, some of which are covered in considerable detail in other parts of this paper. I will therefore refer here to only one or two examples of particular interest at present.

Idle mines and plants represent a waste of capital, a valuable resource. To use this capital productively again in a world of stiff competition requires the ability to sell the product. The efforts of Canadian mineral counsellors and trade commissioners abroad (as well as other export promotion programs of the government) are directed towards increasing Canadian sales, thereby utilizing this idle capacity. To the extent they are successful, we may look on them as a government initiative for increased productivity, especially at a time such as the present.

EMR is also working in several other ways towards improved market access in the longer term. First, we are working with industry to obtain and share better market information. Secondly, we are seeking reduced tariffs and a relaxation of non-tariff measures. Thirdly, we are attempting to exert a greater influence on Canadian trade policy and other policies, including the decisions of international financing institutions. Finally, we are undertaking, in 1984 and 1985, a series of specific mineral market missions to major producing and consuming countries. Federal government officials (and in some cases Ministers) will be accompanied by representatives of industry, together with those of appropriate provinces and trade unions.

Another area where governments have given policy support is in the provision of job training. The Province of Ontario has taken the lead here in developing, in close consultation with industry and with technical training schools, a modular training program for miners. Interest in this program is growing, and variations on the Ontario model can be found around the country. As miners learn the various parts of their job, they are developing a common core of qualifications which should enable them to move more easily from job to job. Doubtless, as they learn their job in a standardized and efficient manner, their individual productivity and safety will be enhanced.

The Province of Manitoba has designated the job of miner as a trade. It has consequently established apprenticeship training for miners and has set a uniform basic level of skills for the trade. Manitoba's 3-year training program, which includes 16 weeks of classroom attendance, enables the miner to earn his journeyman papers following a successful completion of the trade qualification examination given by the province. The program sets standards that should facilitate skill transfers between jobs and between different mine sites.

I would like to outline here a final example of policy support. It is a major new initiative which is under way right now as a cooperative venture between my department and the provinces. You are aware that under the government reorganization of 1982, federal regional development activities, formerly concentrated under DREE, were to become the business of all line departments including EMR. Previously, DREE's General Development Agreements, which expire at the end of March 1984, provided a general framework, and there were subsidiary mineral development agreements with several provinces. These agreements in general called for cost-shared programs, largely consisting of geoscience, which were administered by DREE and delivered by the provinces. Several major successes have been attributed to the agreements, including initial work which led to the discovery of potash in New Brunswick.

The new arrangements call for umbrella agreements, called Economic and Regional Development Agreements (ERDAs) which are to focus on the joint economic priorities of the provincial and federal governments. These sectoral priorities will then be promoted or implemented under bilateral agreements between the sectoral departments involved. Late in November, the first set of these agreements was initialed for Manitoba. The ERDA was accompanied by a general planning agreement and by a Mineral Development Agreement. Clearly, mineral development was identified by the province and by the federal government as a priority in the Manitoba context. The agreement calls for the expenditure of nearly $15 million by the federal government and nearly $10 million by the province over a 5-year period in a jointly-planned, coordinated program. The program contains a major component of geoscientific data gathering, interpretation, and dissemination, of mining and metallurgical research and development studies, and of economic studies, all designed to increase the flow of this indirect but vital government support for our mining industry. The program is managed and coordinated by a federal-provincial management committee.

It is too early to say in which other provinces the same high priority will be attached to mineral development. However, EMR is in serious discussion with at least seven of the ten provinces, with a goal broadly to enhance opportunities for mineral development over the next five years. Details will vary considerably from province to province, depending on the specific needs and opportunities identified in each region. However, if the Manitoba pattern is repeated, I expect most of the agreements to make reference to geoscience, research and technology, and economic studies. I cannot give a firm estimate at this time, but if current proposals are approved, it appears that the total federal contribution over the five years will be substantial. If so, I regard this as a major new recognition of the importance of minerals to regional economies and a notable government contribution to the future well being of our mining industry.

Direct Financial Aid for Activities to Enhance Productivity

Two federal initiatives that have recently been used by many mining companies under the Canada Works program are Section 38 of the Unemployment Insurance Act and NEED, both administered by the CEIC. Although designed primarily to ease unemployment, they have served to help companies undertake useful work during periods of shutdown or layoff. Under the program, mining sector employees have been able to do development work, refurbish facilities, perform environmental clean-up etc. This assistance puts the mine on a better cost footing when it reopens, and it is immediately ready to take advantage of economic opportunities. Also, the programs have helped employers to maintain a productive workforce intact, thereby keeping turnover and separations to a minimum during the layoff period, while allowing workers to keep their skills honed. This latter point is an important one for employers, if they are to be successful in achieving productivity gains which the new international competition is demanding of the mining sector.

The major federal program of direct financial aid to industry is the Industrial and Regional Development Program (IRDP). It is administered by the Department of Regional Industrial Expansion (DRIE).

Support is made available for:

- industrial restructuring;
- marketing;
- modernization and expansion of existing operations;
- the establishment of new ventures;
- improving the industrial development climate;
- innovation.

In the case of innovation and modernization, both intimately connected with productivity enhancement, eligible projects can include:

- consultant studies;
- development of new products or processes;
- technological capability;
- development and demonstration projects;
- design;
- investment for modernization and expansion;
- adaptation of microelectronic/electronic technology.

Depending on the geographical area and the type of project, from 25 percent to 75 percent of eligible cost can be contributed by government. Assistance is not available to primary mining projects, but is available for processing. Perhaps the reason for this exclusion is that the federal government recognizes that mineral resources is an area of provincial jurisdiction. Some of the provinces, however, have grant programs to assist in the costs of mineral exploration and mine development.

Other forms of financial aid are also available through provincial governments, which have often provided electric power at especially favourable rates, or other infrastructure items, usually on a case-by-case basis, to selected mining or mineral processing projects. To the extent that this assistance reduces the capital or operating cost of a mining or processing operation, it provides scope for productivity-enhancing investment by the corporation.

Finally, both levels of government have in selected cases been prepared to examine applications for aid from individual enterprises.

Two recent examples are the federal aid, with some assistance from the province or territory, to Baie Verte Mines and Cyprus Anvil Mining Corporation. At the provincial level, a grant was announced in January by the Quebec Government to assist Noranda Mines in developing its deep copper orebody at Murdochville in the Gaspé. I can offer no exact criteria as to how such cases are judged, but generally assistance has been provided when in each case a productive workforce was held together, at least partially, through a transition period.

I have given a very brief overview of the sorts of government initiatives that are available, without providing much detail.

I should also note that governments sometimes impose disincentives. Some of these are built into our tax system. To the extent that provincial taxes and/or royalties exceed the 25-percent federal resource allowance, the industry can be subject to double taxation on a portion of its income. It can also be argued that the progressive or graduated tax on profits imposed by some provinces is a disincentive to increased productivity since it removes part of the reward for improved performance. Similarly, high interest rates, which depend at least in part on government policies, make it difficult for our companies to finance productivity improvements.

Also, governments, for reasons of public policy, impose a variety of extra non-production-related costs in all industries, such as payroll taxes, unemployment insurance, pollution control costs, and the like. These may reduce company cash flows and thus diminish the amounts available for investment aimed at increasing productivity. The mining industry seems to be a particular target for environmental groups. In this connection, the Mineral Policy Sector is working closely with the industry, the provinces, and other concerned federal departments to develop a nonferrous smelting strategy that we hope will identify ways to enable our smelters to modernize and become more productive, while reducing their output of sulphur dioxide to environmentally acceptable levels, without imposing overly burdensome costs on them.

As to the future, I can only speculate. I hope and believe that our new mineral development agreements will help the industry enhance its productivity. I am sure that there are other new initiatives that we might take. I would like to collect any ideas that may come from this seminar, and I assure you that your suggestions will be carefully considered. There are probably possibilities for closer collaboration in research and the development of technology that Dr. Whitham will want to explore. However, it may also be possible in a broad sense to provide a better policy and economic setting in which industry and labour can function to increase productivity. Finally, it may be useful to offer direct assistance in special cases where individual circumstances justify doing so.

INDUSTRY NEEDS FOR PRODUCTIVITY IMPROVEMENT

William James

It doesn't take a weatherman to know which way the wind blows; and it doesn't take a financial genius to know that the mining industry in Canada and around the world is in trouble. We all know the story: consumption for most metals was growing by an average of about 6 percent per year during the 25 years following World War II; now it is projected to grow by about 2 to 3 percent per year for the remainder of the century. The deep recession of the past two years has compounded the difficulties confronting the mining industry: prices have been falling or have steadied at unsatisfactory levels. Many mining companies have just experienced two or three consecutive years of operating losses.

The economic climate is beginning to improve for us, but the upward climb is slow and laborious and the future is regarded more with caution than with optimism. In these circumstances, it is tempting to look for malevolent forces upon which to blame our troubles and for scapegoats to bear the brunt of our failures.

It is easy for us today to regard the past with disdain, to judge the mining industry and the individual companies that make it up with the sanctimonious wisdom of hindsight. Who today would commit hundreds of millions of dollars to develop a laterite nickel deposit in Guatemala or the Dominican Republic? Well, 20 years ago, when nickel consumption was rising by 6.5 percent a year, when existing capacity was insufficent to meet projected medium-term demand and when energy was abundant and inexpensive, the development of technology to treat laterites was viewed, without noticeable dissent, as a passport to unending prosperity. Who then envisioned the 10-fold increase in the price of oil and the sharp drop in consumption growth and prices that would have the twin effects of making most laterite operations uneconomical and saddling the world with extensive overcapacity? If anyone has such visions 15 or 20 years ago when development commitments were being made, they were not telling the mining industry or those who invested in it. And who was complaining about high production costs, when you could sell all the nickel you produced at a reasonable profit? And if productivity was going down, why be concerned when the price was going up?

Good economics demands a balance, a dynamic equilibrium. And such an equilibrium existed in the 1950s, '60s and early '70s. What we regard today as excessive waste in our operations was not regarded as waste 15 years ago. If your income is high and getting higher, you might trade your Chevy for a Cadillac. Your transportation costs will rise - in effect, you will be getting less productivity for your transportation dollar. Is that foolish? Not if you can afford it.

And back in the good old days, we could afford it. Were our workforces too large? Did we have too many miners, too many managers, too many geologists and engineers? By today's standards, yes, we did. But by the standards prevailing at the time, we did not. They were luxuries, but they were affordable luxuries. The large staffs, the jobs we created, and the livelihoods we provided were the natural outcome of the wealth we had created. They were analogous to the dividends paid to shareholders. Everyone benefited. And at the time it was good.

Today, we are suffering, and looking back, we realize that we may have been living in a fool's paradise. If there is anything truly disturbing about that, it might be the slowness with which the industry, as a whole, recognized its plight and took appropriate action. We did not want to believe that the monetary crisis of 1971, the energy crisis of 1973 and the recession of 1974-75 were signs of fundamental changes in our industry that would require a radical response. It took the devastating recession of 1982 to bring that message home.

From that point on, however, the industry has no reason to chastise itself. Mining companies, acting individually in accordance with a balanced sense of enlightened self-interest, took the necessary measures to reduce costs and increase productivity. You have heard, or will hear, from other speakers the details of how this was accomplished at their companies. Running across the board are workforce reductions, curtailment of all but top-priority exploration and development projects, and general cost management. In effect, we as companies have traded in our Cadillacs for Chevrolets. At least in Canada, you will find a marked increase in productivity.

At Falconbridge, we have made extensive cutbacks in the workforce of operations throughout the organization. At Sudbury, we have gone from about 4,000 employees in June 1982 to about 2,700 today; at the refinery in Norway, from 1,250 to 950; at the ferronickel operation in the Dominican Republic from 1,900 to 1,050; and at the head office in Toronto, from 250 to 122. And we have made these cutbacks without sacrificing current production. In 1981, before the cutbacks, we produced 62.7 million pounds of nickel from Sudbury ores; in 1983, we produced almost as much, 61.9 million pounds, which will rise to more than 70 million in 1984. In 1981, the nickel content of the ferronickel shipped by Falconbridge Dominicana amounted to 41.2 million pounds; in 1983, that rose to 46.7 million pounds, despite a 45-percent reduction in the workforce. In Sudbury, the pounds of matte produced per person per hour rose by 24 per cent in 1983 over 1981. In the Dominican Republic, the output per employee rose by 87 percent during that same period.

These productivity gains could not have been achieved without extensive cutbacks in expenditures for research and development. The mining industry, however, recognizes the vital importance of these activities if we are to remain a competitive and thriving industry in the years and decades ahead.

Industry has responded to this challenge by taking various measures to pool its resources. Hdrk Mining Research Limited, a joint-venture by four major mining companies with underground sulphide operations, was recently formed to conduct major research and development on new mining technology, methods and equipment. Each research project will be directed by a member company, and costs will be shared among the four companies. In a separate initiative, plans are being formulated to establish an independent nickel research and market development institute to promote the use of nickel-containing products, to carry out nickel research and development work and to discover and disseminate technical data on nickel. These two programs will complement the existing activities of the Mining Industry Research Organization of Canada (MIROC), and result in more productive use of the limited amounts of money that individual mining companies are able to allocate for research and development.

Another important contributor to the increased productivity within the mining industry has been the general recognition by labour of the severe economic conditions we have been facing in recent years. The demands of organized labour have been more moderate and reasonable, and cooperation between unions and management has been getting better.

The productivity improvements, plus ongoing cost-management programs throughout the organization - what I like to refer to as our no-frills operation - have brought about significant reductions in the cost of producing a pound of nickel. But these reductions, which, after byproduct credits, amounted to 33 percent in our nickel operations, have been barely sufficient to bring us to the break-even point.

To earn regular profits, the price of nickel will have to rise or we will have to find further ways of cutting our costs. Since we have no control over the former, we are continuing to concentrate on the latter. And that may present some problems. First, some of the cutbacks we have made can only be temporary. Mine development, requiring substantial expenditures, must be resumed to ensure future production. That means spending more money, not less. And eventually, we will have to increase expenditures for exploration if we are to replace depleted ore reserves.

How much of these expenditures will be funded out of earnings and how much will require new investment will depend largely on the price of nickel. Unfortunately, we do not always have the luxury of time; we cannot always afford to wait for market conditions to improve before making necessary expenditures. In the past, we would solve that problem by borrowing. But that option is no longer available. One of the effects of the recent recession was to exhaust our borrowing capability; another was to burden us with overwhelming debt service costs.

An effective solution to the twin problems of a shortage of cash and a prohibitive debt was to go to the street; to seek new infusions of capital in the equity market. In the past 14 months, we made two stock issues. The first, in January 1981, netted Falconbridge $104 million; the second, just last month, brought in about $16 million. These issues are significant, not only becauses they provided Falconbridge with needed cash, but because the response from the investment community was so swift and so positive. The issues were sold out in a matter of hours, and the price we received for our stock exceeded our initial expectations.

It was reassuring that Falconbridge was so highly regarded by the investment community, and that the overall climate for investment was so attractive. It indicated that the efforts of industry, not just Falconbridge but industry as a whole, to tackle the problems of productivity, cost-management, and competitiveness, are beginning to restore investor confidence. This is vital. We are not out of the woods yet - at least not the mining industry. We have survived the toughest times since the Depression of the 1930s, but the struggle for survival is not over, and the struggle for long-term success is just beginning.

A major obstacle, particularly for Canadian nickel and copper producers, is the nature of our competition. Many governments offer substantial direct or indirect support to producers in their countries. We estimate, for example, that about 40 percent of the world's nickel production receives such support. As a result, many high-cost producers which should have been driven out of the market by low prices are still in there, driving the price of nickel even lower.

In this kind of market, being a low-cost producer does not necessarily ensure substantial profits. This situation gives rise to an obvious question: if the governments of Brazil, the Philippines, and a host of other countries support their nickel producers, why does the government of Canada not support us? Should we not receive direct subsidies or such other support measures as reduced transportation rates or exemption from local, provincial or federal taxes?

The answer to that question is two-fold. First, in a sense, the mining industry, like most other components of the private sector, already receives some form of government assistance. Grant programs have been established to encourage research and development, apprenticeship training, and job creation. We in the mining industry support such programs. They are an investment in our future. Encouraging R and D will eventually lead to improved production methods, higher productivity, new product development or the opening of new markets. Encouraging the training of apprentices or the creation of marginal jobs ensures that we possess an essential ingredient of any industrialised nation: a highly trained and skilled workforce.

Now to the second part of my answer: government support to cover losses does not make an industrial operation more efficient, and in the long run becomes a drain on the overall economy of a nation. Greater operating efficiencies, if they can be achieved, offer much better hope for long-term profitability and job creation. If Canada's mining industry cannot achieve profitability on its own merit, then it should cease to exist. It is not a sacred cow to be supported at all cost, or at the expense of other potentially profitable industries.

This is not to imply that government does not have a role in the future of the mining industry, or that the mining industry has no future. Neither contention would be valid. That there is a future for the mining industry in Canada - a future as a profitable member of the private sector - is apparent from the very success that the industry has achieved so far in its struggle against severe recession and fundamental shifts in supply and demand for many of its products.

Establishing the role of government is more contentious, confounding philosophers, politicians, social planners and business people. It would be polite understatement to say that there is no consensus. There is, however, a middle ground - a line down the centre of the road - that would border, if only tangentially, on most positions and give a general delineation of the role that government could, or should, play in our pluralistic society.

The broad strokes of that outline come from the man who has led our government for 16 years. Amid the euphoria of his first election victory in 1968, Prime Minister Trudeau intoned: 'Governments alone cannot produce a better country. That will require the collaboration and participation of everyone.'

Put another way, we should not turn to government either as a panacea or as a scapegoat. Government is not responsible for our well-being as individuals or as corporations; but our well-being cannot be achieved without responsible government.

On the more specific issue of government involvement and intervention in the private sector, I would like to refer to the November 1981 report of a committee of Cabinet chaired by Finance Minister Allan MacEachen. Titled 'Economic Development Canada in the 1980s', the report said:

> We must carefully examine our regulatory systems to ensure that the rules are clear and the procedures efficient, so that they guide business enterprise rather than inhibit it. We must also ensure that our laws which govern mergers, investment, competition and commerce are in tune with modern business practice, so that they facilitate economic expansion rather than burden initiative.

What that passage describes is a partnership. It may not always be a willing or a happy one. How many times have I and my business colleagues damned government intervention and pleaded for government to 'get off our back?' How many times have civil servants and politicians chastised business for its corporate selfishness? But between those fits of pique, we - business and government - do manage to accomplish a great deal together. By and large, we make that partnership work.

It is not a perfect partnership. Far from it. But how well it succeeds or fails depends on us, on both sides in the countervailing balance of government and private enterprise. That balance consists of three primary weights: taxes, imposed fees to finance government-initiated programs, and regulations to control the actions of business.

When these weights are piled too heavily on one side - when business taxes and other government-imposed costs are too high and when regulation becomes too restrictive and expensive - everyone suffers. Operating expenses for business and taxes for everyone become higher; Canadian goods and services cost more and thus become less competitive on domestic and international markets. The outcome is an inability in Canada to generate sufficient jobs and income to finance social programs and protect the national well-being.

There is concern in the mining industry that the balance has indeed been tipping too much to the side of high taxes and other government-imposed costs. The Mining Association of Canada in its recent submission to the Royal Commission on the Economic Union and Development Prospects for Canada, stated that:

> Government cost burdens resulting from regulatory requirements, taxes affecting the costs of labour, energy and purchased goods and services, and mandatory contributions to legislated programs have dramatically increased the share of industry operating costs attributable to government initiatives ... Estimates, admittedly rough, suggest governments are now the industry's largest source of operating costs, accounting for between 27 and 36 percent of annual operating expenditures. Government regulatory requirements and procedures also increase the cost of new developments as they add enormously to the initial cost of capital investment. Finally, corporate income taxes and royalty payments account for about 50 percent of profits.

This is not, however, a static situation. Increasingly, government and industry are talking to each other; we are communicating; we are listening to each other, developing greater mutual trust and credibility. Things are getting better; relations between business and the federal and provincial levels of government are improving.

Take taxation. Government has taken several measures recently which we regard as helpful. Among these are enhancement of earned depletion. By permitting investors in flow-through shares to deduct depletion against any source of income rather than just resource income, the federal government is encouraging the public to invest in equity issues. This is a significant factor in helping small companies raise money for exploration. This is especially important in view of the fact that smaller companies have found most of the mining deposits in Canada.

The federal government's scientific research tax credit (SRTC), which gives a 50-percent credit to investors, has already proven to be a significant factor in raising capital to finance scientific research.

It should be easier to finance capital projects as a result of the federal share purchase tax credits, which enable investors to use a company's investment tax credits.

Increasing the number of years from 6 to 10 (back 3 and forward 7) over which losses can be deducted from federal and provincial taxable income should ease the effect on industry of the recent economic recession.

In Quebec, the corporate tax rates have been reduced from 13 per cent to 5.5 per cent, and Quebecers investing in exploration in their province are now permitted to deduct 66 2/3 percent of exploration expenses.

The tax regime still has shortcomings that should be addressed by both the federal and provincial levels of government. Here are some of them.

- The new rules for investment tax credits enable a company that cannot use a tax credit to receive 20 percent of its credit in cash. However, a company with current losses still loses 80 percent of the intended benefits. Similarly, the benefits of an earned depletion deduction can be deferred so far into the future as to have little present incentive value. A system of cash grants to give businesses their full investment tax credit and the full value of their earned depletion deduction in the year of investment would improve cash flows on new projects and provide real assistance to their financing.

- The present mandatory deduction of exploration and development expenses before loss carry-forwards may have the effect of denying any tax relief for millions of dollars of business losses. To make this deduction optional, like capital cost allowance, would eliminate a major inequity in the tax system and would cost the government relatively little.

- On the provincial level, mining tax acts should be amended to allow deduction for loss carry-overs and interest expenses, to accommodate joint ventures, to facilitate corporate reorganizations and to recognize expenses incurred in flow-through share and earn-in arrangements. These measures should encourage new exploration and development, eliminate unnecessary complexity and abolish inequity.

Government imposes costs on industry in ways other than taxation. Social programs financed by employer contributions and government regulation add significantly to the cost of doing business. These activities to achieve broad social ends are laudable; but to be effective, they must not strangle industry. There has been a tendency in recent years to extend many of these programs and regulations in unfair or counterproductive ways.

Worker's Compensation, for example, has an essential place in industry. There has, however, been a tendency to regard Worker's Compensation more as a social benefit than an insurance plan to compensate employees for work-related injuries. Professor Paul Weiler, in his study, 'Protecting the Worker from Disability: Challenges for the Eighties,' submitted to the Ontario Minister of Labour in April 1983, favourably discusses the idea of having the Worker's Compensation Board compensate employees for lost wages due to injury regardless of whether that injury was work-related. Society may judge such a benefit as being worthwhile. But, as Weiler pointed out, it should not be financed by employer contributions; the cost of compensating victims of nonwork-related injuries should be borne by the general public.

Nonetheless, Worker's Compensation as an industry-financed social benefit is coming, not by legislation or design, but by an apparently generous observance of the rules. Because unemployment insurance pays about $100 less than Worker's Compensation, there is frequently an increase in WCB claims when lengthy shutdowns are anticipated. This was the case in Sudbury when nickel operations were shut down for the last half of 1982 and part of 1983. And it occurred again when a rumour spread through one of our mines during the week of June 20 that our planned two-week shutdown last July was going to be extended. That week, we had a significant increase in compensable claims at that location. The result of this is that Falconbridge and other companies are paying higher WCB assessment rates that are based, not on normal operating conditions, but on an anomalous situation created by unusually harsh economic times.

Government regulation regarding occupational health and safety is an area where government intervention is becoming counterproductive. Falconbridge supports government action that effectively promotes the health and safety of industrial workers. Recently, however, there has been a proliferation in the number of substances designated as hazardous and requiring monitoring in the workplace. In many cases, this process has gone too far. We must, for example, spend large sums of money and assign personnel to monitor the presence of lead and mercury despite the fact that these substances are not found in anywhere near harmful concentrations at our operations. Such expenditures are nonproductive, they raise production costs, and they divert much-needed human and financial resources that could be used more effectively elsewhere to improve occupational health and safety.

The heightening of public concern about environmental damage caused by industry has produced a clear governmental response. Falconbridge and other mining and smelting companies operate under a haze of environmental regulations. Much of this is sensible; indeed, the emission control order placed on Falconbridge in 1969 by the Ontario Ministry of the Environment has helped spur the company on to achieve additional reductions in the emission of sulphur into the atmosphere. In 1950, 83 percent of the sulphur in the ore was emitted into the atmosphere. Today, less than 14 percent is emitted.

There comes a point, however, when further controls become counter-productive: they could become so stringent that a company would have to choose among meeting the requirements, making severe cutbacks, or simply shutting down. The amending emission control order of December 1983 provides a good example of a regulation that almost went too far, and of the positive results that can be achieved through effective government-industry communication and cooperation. The original amending control order would have placed excessively severe restrictions on ground-level concentrations of sulphur dioxide in the areas surrounding our smelter. That order would have required Falconbridge to shut down repeatedly during the year, at great and unnecessary expense. The regulation did not have to be so stringent to protect the environment adequately. So we sat down with government and talked, and talked, and talked. In the end, we were able to reach an understanding; the restrictions in the amending control order were eased; Falconbridge can now comply without undue cost, and the environment and the population of the area still have adequate protection.

I want to emphasize that, while industry still bears the burden of excessive government-imposed costs, government is becoming more responsive to the concerns and needs of industry. There is a greater recognition by government of the benefits that industry brings to Canada as the primary mechanism for wealth and job creation.

We, in industry, will continue our efforts to seek redress from inequities in the tax systems of Canada and from any excessive costs resulting from unnecessary or poorly administered government programs. But we are doing that today in a more optimistic frame of mind; with greater confidence that openness, fairness and a desire for true cooperation are motivating both government and industry.

The net result of all our efforts - of higher productivity in our mines, of joint ventures to conduct research and development and seek new markets for our products, and of greater cooperation between government and industry - will be a financially sound Canadian mining industry. It will be an industry that will continue to generate wealth for the nation and jobs for its people, not just today and tomorrow, but for years and decades to come.

LABOUR PERSPECTIVE ON PUBLIC AND PRIVATE SECTOR POLICIES NEEDED FOR PRODUCTIVITY IMPROVEMENT*

Paul LePage

I have been listening to your talk of the ills of the companies, the problems of the directors, and the role of the government, and so on, and so I think that now it is my responsibility to bring you the view from the front lines, from a foot soldier dealing directly with the people that are affected by this recession. I want to deal with how these people are going to react. If ever they are going to have an opportunity for change in industrial relations, I have a gut feeling that now is the time. Some of the things I am going to say may not be 100 percent in line with the Canadian trade union movement in general, but I want to tell you what is happening, and I have to regionalize it, because all my dealings are in the Atlantic region.

First I want to tell you that our union (the United Steelworkers of America - USWA) used to have 1,400,000 members, of whom we have so far lost 400,000 members. We have accepted the fact that we have lost them for good; the industry is not in a position to re-employ them, so we really don't see them coming back into the steel industry as we understand it. I am speaking of 400,000 lost jobs. I used to represent 23,000 people in the Atlantic provinces. I am down to around 6,200 right now, and all the rest are on layoff.

Let me tell you the effects of these layoffs, so you will know exactly what is going on, so you have a gut feeling as to how the workers feel when these decisions are made. I will start from Labrador first, in the iron ore industry. Look for instance at the competition from Brazil. I checked with External Affairs, and heard that the American government is prepared to allow Brazilian iron pellets to be sold to the American markets because of the money owing by Brazil to the American banks. We are just going to have to accept the fact that 50 percent of our production is going to be cut, and for a long period of time. The only reason, I suspect, we are still running as high as 50 percent of capacity is because some of the companies in the United States fear some labour and political instability in Brazil, so they keep the Canadian mining operation going as a back-up.

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* Prepared from a transcript of Mr. LePage's presentation.

Now, what happens when you lay off someone? (I have to get out there and face these people in the hall, and you're looking at maybe 50, 100, or even 2,000 people. You have talked about your losses today; I want to talk about theirs.) If a worker bought a home for $60,000, and the re-sale value is only $40,000, and he owes on that home, he leaves there without a job and with a $20,000 debt. If he has a trailer that he bought for $18,000 or $20,000, the best we could get for it is probably $8,000. So all of his equity is lost; he has lost everything. He leaves there for good, and he goes back to Newfoundland, or wherever. For the first year it will be UIC, and then he goes on social assistance.

The reason I want to emphasize the social costs to you is that, somewhere down the line, we have to find ways and means to start eliminating them, because somebody is going to have to pick up the tab. Our provincial governments are not going to legislate slavery, they are not going to allow people to die, or not get hospital care, and so on; and they are going to make sure that people have food on the table; somebody is going to pick up the tab.

Now let's look at Bay Verte. It was hoped that they would get some subsidies to keep it going, but it has closed down. And when you close down Bay Verte, you close down the community. It's finished. I went in to that hall and talked to those people, and they have nowhere to go. They all live in company houses, and the company is telling them they have to vacate the premises, on top of losing their jobs. So then it becomes a responsibility of the provincial government to provide some lodging and some food on the table, and that again is more social cost.

I can take you into Cape Breton and tell you the same story, and I can take you into New Brunswick. The social costs were far greater than just the losses of the companies. We have 60 percent of the people unemployed there, 60 percent of the people who first will use up their unemployment insurance and then be on the provincial rolls for social assistance.

That is what is happening in eastern Canada. We also have a large group of people laid off in Sudbury, and in other parts of the country as well. These are very serious situations. So what have we done? What can labour do in order to help you? What can you do to help me? I believe that this is the opportune time to start looking at some type of partnership in trying to bring about what I call joint survivorship.

How can we all survive? If you don't help me, somebody else is going to have to pick up the tab. It is difficult, because if you as companies get involved in the effects of technological changes, and if you have to pay all the social costs, there will then be a disincentive for you to invest in technological change, which would end up by compounding the unemployment problem. And you would lose your competitive position. So in some way or other we are in a bind here. Let us examine the situation, and let me tell you what workers are looking for.

I am glad that Bill James spoke before me, because when we were involved in Brunswick (and he will remember this like it was yesterday) he said we had cash flow problems, something like a million dollars worth. He said 'I've got to lay off 200 guys. The money is not there'; and we said, 'This is a very serious situation, and there are no easy answers. What can we do, what can labour do, in order to help you? And what can you do to help us?'

At the time, I got up one morning and happened to watch Canada AM, and I can remember union people in Ontario saying 'There's no way that we'll ever take work-sharing. Work-sharing, that's poverty-sharing', they said. And I told my representives at the time, 'Don't make that statement. Shy away from that statement and allow me to examine it'. So we examined it, and I put it before Bill and his people and I said 'We'll go on the work-sharing program. You save me the 200 jobs and I'll give you a million dollars'.

Those same 200 people are working there today. That was the first work-sharing job in Canada. The funny thing about it is, we had the best absenteeism rate, we broke every production record in the history of that company, and we still saved 200 jobs. And he got his million a month.

I had some opposition from the head office of the labour movement at that time, but I said, 'Whatever you do in Ontario or in B.C. or wherever, my responsibility is to the workers in eastern Canada and I feel I have made the right decision. We're going to try the work-sharing program'. And we did. Essentially, the company said 'We will secure your jobs if you help us'. And the workers set about and broke production records and made sure that the company had the cash flow it needed.

But after that, something happened that was difficult for me to try to rationalize, because there had been a real partnership working at that time: it wasn't 'them and us', it was 'we must work together in order to make this thing work'. But once the company started making profits, we didn't have that partnership anymore. They had 27 illegal strikes in one year. Then the company put a package on the table that was the biggest that I have ever negotiated. It was the best collective agreement I had ever seen, and we had a five-and-a-half-month strike!

I couldn't believe it. What was happening? The attitude at the beginning of the work-sharing program had been of a partnership with the company, and of understanding with their immediate supervisors. Everybody was working together to make the company profitible. Relations were good. But as soon as the company took back its management rights and said 'There is only one way to do it and that is my way', all hell broke loose and things have been wrong ever since. The company has tried all kinds of different programs in order to put it back together, but with no success.

So we tried to come up with another program that would bring that partnership back again; some people call it gain sharing. What we are doing now, in order to make the company profitable, is that the employees now working in production groups, on the shop floor, or underground, or wherever the case may be, are prepared to pass along their ideas to the company, in the interest of making it more productive. The company signed a memorandum of understanding, agreeing not to lay anybody off, provided we meet production requirements and reduce costs by x number of dollars. Ever since the program was put in, we have reached our targets. Nobody has been laid off.

I want to suggest to you that gain-sharing programs will work. I honestly believe that, with this recession, we can look for major changes in the industrial relations scene in this country. I think the companies can develop a partnership with the workers. I am convinced of it.

Here is how you set up a gain-sharing program. Take a base period, say the previous twelve months. Say we produced 9000 tons a day at such and such a recovery. You must then improve the recovery, you must reduce the cost of operation of the department, you must increase the output. If the employees do better than in the base period, there is a financial reward. However, if you use the same measure of improvement each year it would be self-destructive, because the improvements get harder and harder to attain. From time to time you have to adjust things so that there is always at least a 10-percent earnings potential.

The way it works is that the individual worker is prepared to work with his foreman and his other co-workers to find ways and means of improving the production of his particular work station or that of his counterparts. Then he goes to a steering committee. Naturally, the company makes the final determination, if a suggestion requires a capital expenditure. The manager makes that decision, but he looks at all of these suggestions and, if he finds that they are within reason and are going to help his operation, he will make that capital investment.

The split is 75-25 on all the profits, or all the gains. The company gets 75 percent because they make the capital expenditure. With this program we were successful in saving 200 more jobs, when the company closed the open pit but was able to absorb the labour force.

In exchange, in the collective bargaining process, the company has agreed to put a certain amount of money into the wage package to be made available to employees affected by technological change. For example, if a worker aged 60 is affected by technological change, he can get an early retirement. Using this fund that the total work force had put together, we could buy off the actuarial reduction up to normal retirement. Usually it's 2 percent per year up to normal retirement. If the worker was going to lose 10 percent, then, using this fund to make up the difference, he could take early retirement, and it wouldn't be necessary to retrain him.

We have found that gain sharing is a very good idea. Of course we didn't buy it lock, stock and barrel, or without a lot of investigation. I went to MIT, and to some of my U.S. counterparts in the labour movement, and learned that plants that didn't have the plan were less productive and were always in trouble. With the plan it was much easier for union representatives to service that particular industry because membership meetings weren't taken up with arbitration cases and grievances. Instead, they were talking about productivity, and about how they could improve the operation of their plant. It was a whole different attitude.

They are working hard in the USA to promote these programs. There was a conference held in Phoenix on this line not too long ago, and will be one in Cleveland in May. They are going on in every state, and this is the type of program they are putting in.

One of the problems I have been confronted with, believe it or not, is that the front line supervisors are opposed to it. Let me tell you a personal experience. When we put the gain-sharing program in and we wanted to increase the production, one of the guys called me up. He worked underground - he pulled a 60-ton truck, I think it was - and said that the mine captain told him to take only 32 loads to dump down the ore pass. And he said 'I thought that the union met with the company last week and agreed that we were going to increase production. But he's only going to look to me for 32 loads'. I said to him 'You give an honest day's work for an honest day's pay. You go out and perform your work, go out and do it and give him an honest day's work'. And he put out 68 loads.

Now let me just follow this problem. If you really investigate this thing, you have to investigate it right down the line. The day that all the workers become self-disciplined, they work as a team, and then why do you need a foreman? And some mines thought exactly that, and got rid of all their staff. But that was wrong. It may seem strange that a union guy is going to defend a foreman, but getting rid of him doesn't make any sense to me. The foreman is still essential, but with gain sharing he can be a foreman, instead of being a psychiatrist, and handling grievances, and everything like that. He can make sure that the materials needed for the work are there: for the guys that paint, for example, that the spray paint and the spray guns are there. And he can coordinate the work so the team is ready to go to work at 8 o'clock and they are there until 4:00. That is actually what the role of the foreman is. But it sometimes happens with this program that right away he says 'I'm going to get the axe', and so he tries to sabotage the plan. I have had to go to a company and tell them, 'You've got a worse problem than I have in getting this program accepted. You are going to have to get your foremen to accept the fact that the workers want to get more tonnage because they want to save their jobs'.

If you decide that you want to put this kind of program in your plants, to get into this partnership, let me suggest to you that it is going to be extremely difficult. I'll tell you why. The first problem is the adversarial system. I was president of the New Brunswick Federation of Labour for 13 years, and if I were there now during this recession period I would like to be able to call conferences on productivity, the value of technological change, and competitive position in the market place, but I would not be able to, because we have an adversarial system. We have a lot of people out there who really believe in it, and it creates problems.

Let me tell you one of the reasons we are adversaries. It is very simple. I sit on the Labour Relations Board, and we are saying: 'We will give you complete partnership and maximum productivity, but why not give us freedom of association? Why don't you allow me to go and organise workers at a non-union shop and let them join a union of their free choice? Why do you take me through all this litigation and all this 'employer free speech'. Why deny workers the right to belong a trade union? I know the law says that they have the freedom to join a trade union, but I sit on the Board and I know what employer free speech is. I know what it is to see someone who has signed a union card being cross-examined on the witness stand. It can be pretty unpleasant, to put it mildly. No wonder the union rep says, 'You call that labour management relations, when the basic thing we want is freedom of association and you don't even give us that?' That's why you've got an adversarial system. That's why, as president of New Brunswick Federation of Labour, I could never devote my energies to productivity, competitive position, and so on, because I am denied the basic thing that was given to me 60 years ago, and that's the freedom to belong to a trade union.

Let's not kid ourselves; we are denied the freedom to belong to a trade union. We see all these lawyers that come in there and really do a job on the unions. Now, you have heard of some of the ways that non-union shops keep the union out; I can remember management complaining about unions insisting on feather-bedding, but at the same time, management would never fire a guy but would keep him there just so they could keep the union out. So these are some of the things that our guys don't like. And it is hard to understand. I can show you statistics from the United States that show that the union shop is more productive than similar strike-free plants. Why? Because when a worker belongs to a union he knows he is responsible for a certain amount of production. When he goes to the foreman, the foreman doesn't say to him 'I'm the boss and there's only one way to do it and that's my way'. There is that equal partnership on the floor. The foreman is protected by the company and the other guy is protected by the union, and there is some equality on the shop floor. In the United States, where they have put in gain-sharing programs, the union shops have been more competitive than the non-union shops.

What I'm saying to you is that now is the time; I am firmly convinced that now is the time. We have a serious economic problem and we must work together in order to resolve it. There are ways that we can increase productivity and there are ways that we can survive. Let me cite you an example - a real example. I got a call from the manager of a plant that would be about 60-65 years old, and that has since had some new investment. During the war there was a policy that you went there in the morning and you put out x number of units and when you were finished you could go home. You could go there at 8:00 a.m. and be in the tavern by 2:00. This went on for years and years, and they used to put out 15 units per day. Then they hired one of the best industrial engineering firms in Canada and put a stop watch to these guys, did a time study. It cost the company an arm and a leg for that time study. And the result was that the workers worked 8 hours and the company only got 12 units a day. Finally the manager came to me and he said 'How do I buy those two hours, those 3 additional units?' I talked to him about a program which would get him the good ideas from the guys on the shop floor for nothing.

This plan that I'm talking about came out of MIT. (When they offered it free, none of the companies wanted it. Then they set the registration fee at $450 and packed the place. It has to be good, if it costs a lot of money.) All a company has to do, in simple terms, is to say 'If you help to make us more competitive, more productive, and better in the market place, we will work like hell to give you job security'. Now I know that no company will come along and say that, during the life of this agreement, nobody is going to be laid off. That is impossible, because prices can fall and there are going to be some legitimate lay-offs. But if the company is prepared to try and save jobs, then the workers are prepared to work to the best of their ability to see that you are in a good strong competitive position, because it means their jobs. That's what they want more than anything.

I personally believe that collective bargaining will change. Workers won't fear technological change; instead they will fund retraining programs, and will fund money for early retirement. This is the new trend. All they say is 'Accept me as a partner, give me freedom of association. That's all I'm asking'. No more, no less. Very simple.

Now is the time, and nobody is in a better position than we are. We as workers are prepared to join into this partnership, providing you give us the right to exist. So I challenge you to take a serious look at this. We're preparing to do everything we can to make our contribution, and I put it to you: you accept the offer we're making and I guarantee that we'll all gain by it. If you turn it down, you'll pay a price.

PART III

PRODUCTIVITY IMPROVEMENT INITIATIVES

PRODUCTIVITY IMPROVEMENT AT INCO'S COPPER CLIFF NORTH MINE

Eric Kossatz and Walter Curlook

Introduction

At Inco today productivity improvement is an ongoing battle, and the flagship of our effort is the Copper Cliff North mine in Sudbury. It is the focal point in our program to replace or modify concepts and methods and to reassess well-established traditions. What was the need that brought it about? What were the objectives? What objectives were met? And what did we learn along the way?

The roots of Inco's productivity improvement program go back to the establishment of mining research departments at both the Manitoba and Ontario Divisions, in 1979 and 1980. Their mandate was clear: develop easier, safer and more productive mining methods. Then came the Hardrock Research (Hdrk) Corporation, fusing the efforts of Falconbridge, Noranda, Kidd Creek and Inco in specific collaborative programs of mining research.

And then, the drive to improve productivity was accelerated in recent years by the onslaught of low demand and disastrously low prices for mineral commodities. For Inco, then, the challenge to remain cost-competitive in copper and nickel, our two main products, provided a compelling and urgent need. Clearly, Inco cannot set the prices of its two commodities, but can, however, intensify efforts to lower costs. Today, the effort to improve mine productivity remains a driving force at Inco.

The task of lowering costs must be done in the face of demands for increased wages, and in spite of increasing energy and supplier costs. To make quantum improvements in productivity requires fundamental structural changes in every aspect of the operations. So, driven by the need for, and excited by the magnitude of, the benefits that could be derived from productivity improvement, what were the objectives of Inco's program implemented at the Copper Cliff North mine?

Co-authors of this presentation were Claudio Barsotti, Manager, Mines Research, Ontario Division, Inco, and W.J. Moffatt, Senior Research Advisor, Ontario Division, Inco.

Summary of objectives and plans

1. To develop a mining method which would be easier, safer and more productive.
2. To achieve a three-fold increase in productivity (from where it had been when the mine was shut down).
3. To employ and develop a bulk mining method which would provide high output on a continuous basis.
4. To concentrate all production activity on a single level to minimize development costs and ancillary services.
5. To extract all of the ore in a single pass, i.e. to leave no pillars for secondary mining.
6. To assess the magnitude and nature of the fluctuations in output when striving for maximum productivity, as contrasted with assuring a certain level of output.
7. To minimize such fluctuations in output through technical and organizational redesigning.
8. To test new ways of crewing and staffing, and to expand use of multifunctional broadly-trained workers.
9. To test new incentive programs for support and maintenance personnel tied to the productivity of the production mines, that will:
    - share the benefits;
    - encourage acceptance of new technology;
    - emphasize teamwork.
10. To demonstrate the efficacy of a 'flat' organizational structure (management-supervision).
11. To take full advantage of computers in all administrative and monitoring functions, as well as in planning.

So, armed with our objectives, what did we have to work with? Most Inco mines are mature, yielding a high proportion of their production from secondary pillar recovery. Some mines have been operating since the turn of the century, many others for more than 40 years. Our deepest mine is over 7,000 feet. The depth of our average mine is about 3,500 feet.

Not unnaturally, new mining methods and equipment can readily be adapted to new mines. More often than not, such methods are designed for high-productivity/low-cost primary stoping. And not uncommonly, less attention is paid to the secondary pillar recovery several years later. Less efficient secondary pillar recovery can often consume the productivity gains achieved through the application of new technology in the primary stoping phase. As well, in recent years, much technology and capital were directed, not towards productivity improvement, but at reducing physical effort and at complying with new governmental regulations. And so it was at Inco.

In an integrated mining-smelting refining operation, the expectation of the mines is the guarantee of uninterrupted delivery of ore. Mining operations were staffed to meet peak demands; capital development was kept well in advance, both actions being labour and capital intensive. And so it was at Inco.

A stable labour force, with many third and fourth generation employees, has both an upside and a downside effect. Traditional ways can become entrenched and change can become more difficult to bring about. And so it has been at Inco.

Achieving quantum leaps in productivity, of up to 300 percent, in the face of such long-standing work habits poses a special challenge. We felt that we could arouse everyone's interest, in the mines sector, if we made a dramatic demonstration of what could be achieved; set an example, so to speak. We turned to the Copper Cliff North mine, which had been closed in 1978 because of low productivity and high costs. If we could turn this operation around, we could set a pattern for other mines to follow. The idea of a demonstration research mine was most intriguing. It is noteworthy that even before implementation of the Copper Cliff North mine program there were positive spin-offs for some of our other operating mines.

Copper Cliff North Mine

The Copper Cliff North mine stands at the northwest corner of the City of Sudbury, one mile north of the town of Copper Cliff. It is one of nine underground Inco mines now operating in the Sudbury basin (see figure 1). All Sudbury orebodies are intimately associated with a layered group of igneous rocks, known as the Sudbury igneous complex. The igneous complex outcrops in an elliptical ring some 17 miles wide and 37 miles long, dipping inward to form a basin-shaped structure.

The copper-nickel deposits occur in one of two ways: in depressions in underlying footwall rocks at the rim of the basin; or, as in the case of the Copper Cliff North mine, within dyke-like bodies known as offsets. The Copper Cliff offset extends up to five miles from the rim of the igneous complex. Figure 2 shows a plan of the mineralized zones strung out along the Copper Cliff quartz diorite offset. Unfortunately, at today's price/cost ratio, many of these zones are not, by definition, ore.

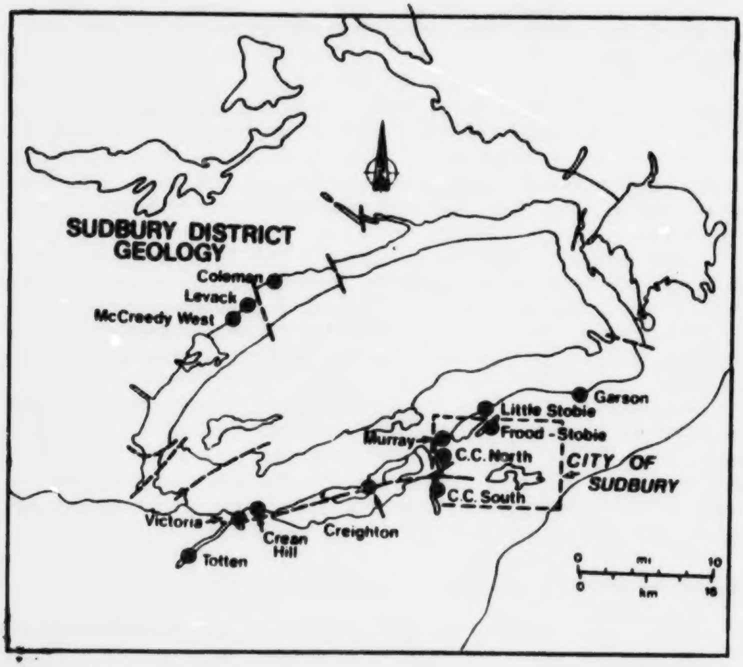
SUDBURY DISTRICT GEOLOGY
Coleman
Levack
McCreedy West
Garson
Little Stobie
Frood - Stobie
Murray
C.C. North
C.C. South
CITY OF SUDBURY
Victoria
Totten
Crean Hill
Creighton
0 mi 10
0 km 16

Figure 1

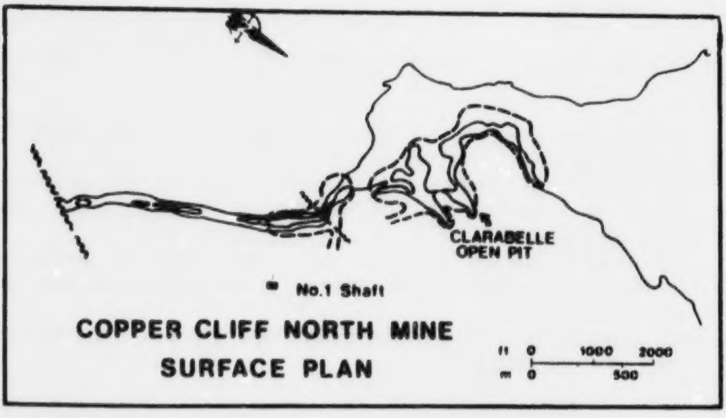
CLARABELLE OPEN PIT
No.1 Shaft
COPPER CLIFF NORTH MINE SURFACE PLAN
ft 0 1000 2000
m 0 500

Figure 2

The longitudinal section (figure 3) shows the general layout of the mine. We chose the lowest levels of the mine, 3600 feet and 4000 feet, for our initial tests. To minimize the number of levels open or developed, all extraction was concentrated on 3935 level only, and the deepest operating section was selected for the initial campaign. Ore extraction would be completed at this horizon before extraction would begin on the next horizon above. As well, the plan called for mining the next successive level without leaving any crown or floor pillars.

The deepest level in the mine - the 4000-foot level - is required for dewatering and for access to the crusher. No underground ore storage is planned, a commonplace practice in conventional mining. Broken ore moves directly to the crusher, from there to the loading pocket, and is hoisted to surface.

The production objective was set at 2,000 T/D with an overall productivity of 18.2T/manshift including maintenance, administrative staff, and external services. For several reasons, the mining method chosen was vertical retreat (VRM). In addition to being a bulk method, it gives excellent fragmentation and good wall support.

Mining is planned as follows (see figure 4):

- first, the primary blocks are mined and backfilled with a mixture of waste rock and cement slurry;
- next, the secondary blocks are mined and filled with unconsolidated rock.

The mining layout is fairly conventional, with some exceptions:

- the blocks are almost 400 feet high, with the employment of a sub-level for drilling;
- the secondary blocks are twice the size of the primary ones, to improve ground conditions and minimize the cost of cement;
- the cement slurry plant is unmanned, with all the controlling performed by the miner underground in charge of back filling;
- all production is to come from two blocks (one blasting, one pulling).

Research Programs

Let me now turn to research programs that are being carried out concurrently with production.

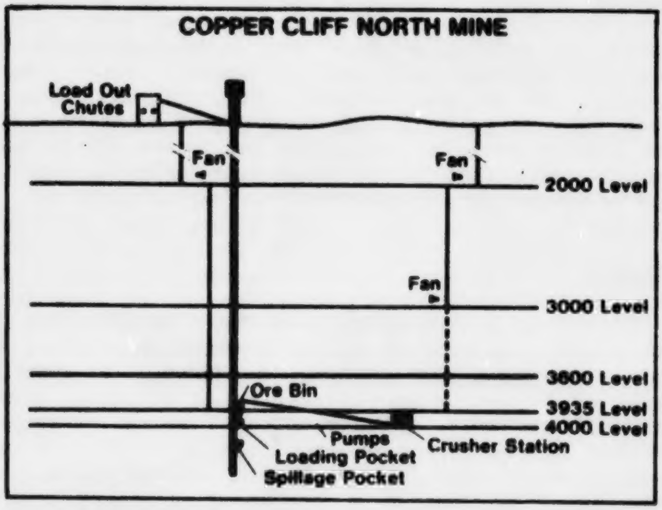
COPPER CLIFF NORTH MINE
Load Out Chutes
Fan
Fan
2000 Level
Fan
3000 Level
3600 Level
Ore Bin
3935 Level
4000 Level
Pumps
Crusher Station
Loading Pocket
Spillage Pocket

Figure 3

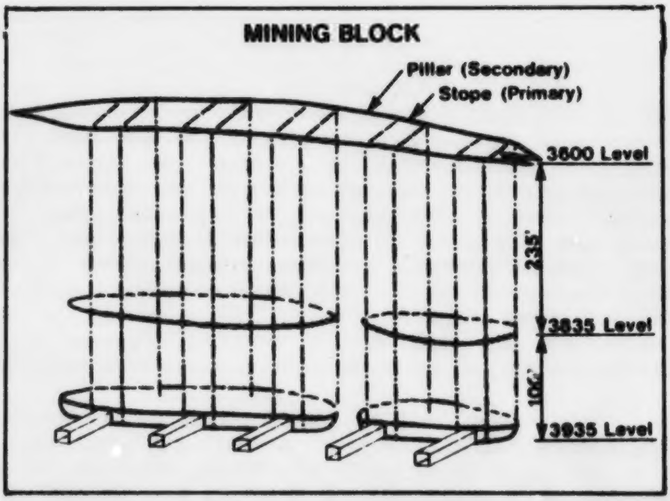
MINING BLOCK
Pillar (Secondary)
Stope (Primary)
3600 Level
235'
3835 Level
100'
3935 Level

Figure 4

Drilling

Today, all drilling is done with in-the-hole (ITH) drills, designed in-house and built in-house. Now under construction is a computerized, fully-automatic ITH drill. When fully operational, this machine will allow us to reduce our drilling force by half, since the driller will be required only to move the machine from hole collar to hole collar, and to respond to emergencies.

Blasting

VRM blasting is now carried out one deck at a time. However, with this type of mining, much of the loading time is spent measuring and priming the holes. If more decks could be blasted at one time, blasting efficiency would improve dramatically. Unfortunately, recent findings concerning the behaviour of explosives in multi-deck applications were surprising. The field of influence of a blast, in inducing detonation of a neighbouring charge, is much greater than previously thought. The research has now turned to the physics of induced detonation. Multi-deck blasting will have to await developments in control of induced detonation.

Ore Removal

All of the broken ore is currently being hauled by two 8-yard LHD units. The geometry of the level and the tramming distance necessitate operation on two shifts to achieve optimum production and productivity. Under development is a high-speed mucker capable of production rates several times that of a scoop or combination of scoop and truck. If this research proves successful, we will either concentrate all ore movement on one shift with a significant reduction in the manpower required for support services, or increase the output per shift with a resulting increase in overall production as well as productivity.

Organization

Innovations in organizational structure are directed at:

- encouraging more effective utilization of supervision;
- providing maximum job mobility, freeing any one employee to perform a multiplicity of tasks;

- creating opportunity for a constant dialogue and feedback into work planning and procedures, by all employees (teamwork).

Effective Utilization of Supervision

The North mine is supervised by a total of five supervisors: two foremen per shift plus one superintendent. Each supervisor, then, has a very broad spectrum of responsibilities. We recognized that the least productive (and most boring) part of a supervisor's day was the time spent on clerical work for record keeping and information gathering. We also determined that the total time spent on this kind of work could be reduced to around 15 minutes per shift from 40 minutes by switching from manual to computerized reporting. Accordingly, the following functions are being computerized:

- time keeping
- force reporting
- job posting
- personnel record keeping
- qualification record keeping
- disciplinary record keeping.

The system contemplates a network of computer terminals located at strategic points in the mine from where the foremen can interact directly with the mainframe computer located in Copper Cliff. This would facilitate his work and eliminate the need for time clerks and key punchers.

In a foreman's day, time keeping has been the most time-consuming activity. We concentrated our efforts on that function, and the computerized system is now in place and working extremely well. We have now advanced to developing information retrieval files related to safety, training and personnel records.

Job Mobility and Assignment

At closure in 1978, employees of the Copper Cliff North mine had been transferred to other operations within the district. Each was given the opportunity to return to the mine upon reopening, seniority being the main criterion. When the philosophy of the program was presented to them, most came back. The average age of the Copper Cliff North mine employee is 47 years, most with 25 or more years of service. All accepted the challenge to become multi-functional, undertake extensive training, and acquire up to 13 job qualifications.

Mobility is another matter. Typically, our miners are categorized according to a large number of well-defined job classifications. At the North mine, with only 33 operating men per shift, the old system would have predicated 26 job categories. Recognizing that each change in classification involves an assessment of seniority rights, review of qualifications, and voluminous paperwork associated with changes of pay, one can appreciate that operating under these standards with such a limited work force would have been a nightmare.

To address this problem, we designed new classifications which combined 26 old ones into 6 compatible new ones. The new system had the following advantages.

1. We now have enough people within each classification that, if someone is missing, he can be replaced within his own group without any need for reclassification.
2. It has combined the job skills to an extent where a person can be moved from job to job to meet the flexibility required in a dynamic mining situation.
3. It has provided job enrichment and higher pay for the individuals involved.
4. It has greatly simplified the administration.

Opportunities for Greater Employee Participation

Employee participation in planning their own work has been abetted by:

- removal of traditional interdepartmental barriers, particularly between operations, maintenance and administration;
- establishment of team organization;
- development of a broader, more comprehensive incentive system.

Removal of barriers was achieved simply by eliminating a number of senior jobs. The mines normally operate with five vertically parallel functional groups that meet at the manager's level (i.e., operating, maintenance, engineering, geology, and administrative). At the North mine, the reporting structure has been changed so that one person is in charge of all production functions and a second person is in charge of all staff functions. There are no other supervisors in the organization except for the mine foremen. This integration has improved communications and shortened the decision-making process.

Teamwork is promoted by the organizational structuring, which groups employees into self-sufficient teams able to carry out a full spectrum of duties. Each team includes operating and maintenance personnel. Each team belongs to either the production or the support group, and each group is supervised by one foremen per shift. All members of the operating department in each team have the same job classification and pay.

In order to further encourage cooperation between support and production personnel, a new incentive system was implemented for the support crews. The support incentive is based on the output of the production crews, who have their own incentive plan based on their own output, so that support personnel have a vested interest in the overall performance of the mine.

Summary

In summary, the Copper Cliff North mine project is a success. The mine was brought back into production on schedule, has begun to meet its specific objectives and will no doubt surpass them by year end.

We are well on our way to a safer, less physically demanding, and more productive mine. However, it is a much more difficult mine to manage because of its inherent production inflexibility and its need to function like an assembly line.

Table 1 shows the progress to date. Although we experienced certain mechanical startup difficulties during the first two months, the operation did, even in this period, double the mine's previous productivity. During the third month the production objective was exceeded. The potential of exceeding the target of 10,000 tons/week is now a certainty. Stope production has exceeded expectations; however, backfill will not be required until after May this year and must yet be proven.

Equally important is the role the mine has played in initiating changes in other operating mines. At one mine with comparable organization, job restructuring and a similar mining method has resulted in a gain of 220 percent in productivity with more to come. Another mine is exploring a production rate of 4,500 tons per day from a single level at below 3,000 feet.

Leadership takes many forms. The Copper Cliff North mine has taken on this role.

Table 1

PRODUCTION/PRODUCTIVITY

	1977 Actual	1984 Objective	1984 Actual Jan. Actual	Feb. Actual	Mar. Actual
Tons/Day	5,162	2,000	1,132	1,115	2,032
Tons/Manshift	6.3	18.2	10.9	10.5	18.9
Lbs CuNi/MS	344[a]	1,030	691	656	1,216

[a] Lbs CuNi/Manshift, factored upwards to equate to equivalent grade of 1984

POSSIBLE INDUSTRY/GOVERNMENT TECHNOLOGICAL INITIATIVES

Kenneth Whitham

Introduction

The relationship of technology to productivity in mining is an important issue for the Department of Energy, Mines and Resources and for the Research and Technology Sector in particular. The subject is sufficiently far-reaching that, in order to address 'possible industry/government technological initiatives' in a meaningful way, attention must be focused on related topics including: the policy environment, the role of the public sector in research and development (R and D), options available to governments to promote productivity improvement, current federal R and D initiatives, future thrusts, the industry/government interface and so-called 'enabling' technologies.

The terms innovation, technology, and R and D are often used interchangeably. This is a great oversimplification. Without going into the detailed Frascati definitions, it might be useful for the purposes of this paper to consider R and D as the fusion of science (understanding of the universe and its physical laws) with engineering (design, energy and materials) to produce useful/usable processes or technologies, which in turn produce useful goods or services. Innovation introduces the important concept of an economically improved technology.

It is usually accepted that future productivity gains will depend upon the investment of capital, the introduction of new technologies, the adaption of the labour force to new skills, and management's ability to use capital, technology and worker skills wisely and effectively. It should be clear that the government in its overall economic and technology policies, and in such initiatives as the creation of the Canadian Labour Market and Productivity Centre, is well aware that productivity is a societal problem that goes beyond purely technology issues. Nevertheless this paper will discuss only the technology part of the solution for productivity and quality improvement, while realising that technology and innovation is only a part, but nonetheless a very essential part, of the solution.

Policy Environment

In a series of policy decisions and documents since 1980, the federal government has recognised the importance of the resource industries in the future of Canada, along with the newer 'high technology' or technology intensive industries. There is, however, some debate about whether Canada should concentrate more on high tech industries and be resigned to a decline of the resource industries, because of cheaper labour and in some cases richer resources in third world countries. The Science Council of Canada has been quoted as taking this line, but others have taken the opposite view.

It is the federal position that technological development and innovation are essential to economic prosperity and that this is true for both the high tech industries such as microelectronics and communications, and mature industries such as the resource industries including the mining industry. Indeed high tech industry can be looked at as simply industry with a more advanced technical base, more R and D and a lower labour content than low-tech industries.

There are two main ways in which Canadian mineral industry can be affected by R and D and technology development:

- R and D can provide the improvements in efficiency and productivity of mining and mineral processing that are necessary for competitiveness in world markets;

- R and D can render obsolete established products and processes, in mining as well as in the more obvious areas such as aircraft and electronics.

To maximize its economic efficiency, the mining industry must have access to, and be able to make use of, world-competitive technology on a continuing basis. To predict the future, both policy makers and mineral producers need to understand the developments in new materials.

Role of the Public Sector in R and D

The federal government is a major source of R and D support of the mineral industry. It has been providing geoscientific support to industry through the Geological Survey of Canada since 1842. It has supported mining and minerals technology since 1907 when the Mines branch was founded to assist the industry in research, a subject with which industry was not at that time very familiar. Indeed one of the paragraphs of the Resources and Technical Surveys Act directs the Minister (of EMR) to 'make such chemical, mechanical, metallurgical and other researches and investigations as are necessary or desirable to carry out the purposes and provisions of this Act and in particular to aid the mining and metallurgical industry of Canada'.

The particular federal laboratory concentrated on for further analysis is CANMET, the Canada Centre for Mineral and Energy Technology, which has evolved from the Mines Branch. CANMET was chosen because it has been designated by Cabinet as the lead agency in both performing and coordinating federal R and D in mining, minerals and metals technologies. Three kinds of direct government R and D have been identified in CANMET's mission, supporting different areas of government responsibility. These can be expressed as follows:

i policy R and D - performed directly in support of federal mineral policies, standards and certification programs;

ii protection R and D - performed in support of the operations of regulatory agencies such as mining inspectorates, AECB, NEB, etc. and also in support of industrial R and D aimed at mine health and safety, effluent control and performance standards for materials;

iii productivity R and D - aimed at complementing industrial R and D to improve the efficiency and productivity of mining and mineral processing.

Much R and D, particularly in areas such as safe, efficient mining, is not exclusive to either protection or productivity R and D. In times when the mineral sector was growing, the productivity interests of the government were essentially long-term, and tended to look at the generic needs of the industry as a whole (or sub-sets of it e.g. gold processing, deep mining), or to respond to either national or regional issues (e.g. New Brunswick sulphide ores, national tailings program). Effort was thus devoted to the development of general principles of processes and systems and to providing the bases for new technologies that would eventually replace existing ones. This public role in productivity complements industrial R and D, much of which must necessarily be of shorter term because of the necessity to show a direct and relatively short-term return on investment.

Clearly, if government and industrial research are truly to complement each other, there must be adequate overlap in time horizons; otherwise, the occasions for communication will be minimal. Consequently there is, in principle, a need for both government and industry to ensure a maximum area of mutual interest, thus permitting the application of the basic knowledge gained in longer-term R and D to short-term industry problems and allowing an appreciation of current technologies in planning those of the future.

When times are prosperous there is a danger that each group will concentrate on its own interests because each has less need of the other. In consequence government R and D in particular may become isolated from industrial productivity, and industry's sense of urgency for constantly improving technology may diminish. Some observers would say this was the situation until comparatively recently.

By contrast, in difficult times the efforts of all tend to concentrate on shorter-term problems. Although government can respond by such a change in emphasis, there is always then the danger that, with decreased industrial R and D and with a conscious government emphasis on the short term, the more fundamental bases for future technologies will be abandoned so that eventually there will be no new technology to transfer.

One of the planning aims of EMR is to determine the best ways in which government can foster and influence R and D for the generation of more productive technology. The distribution of government activities between productivity and other issues is not random: it reflects the various changes in government policies and national attitudes over the years. At one time mining was considered a beneficial industry that provided jobs and prosperity and should be supported. The 1960s saw increasing public concerns over safety and the environment; these concerns brought new social views of the industry, and an increasing effort in government R and D on health, safety and environmental work. However, the recent downturn in the economy and increasing international competition in mineral markets have highlighted the need for urgent improvements in productivity and efficiency, and the possible contributions R and D can make are once again recognized as a major priority by government.

Options available to Governments to Promote Productivity Improvements through Research and Development

In principle, the basic means at the disposal of the federal government to promote R and D and innovation within a sector are limited to:

i regulatory policies;
ii fiscal policies;
iii direct investment, either by joint initiatives or by supportive work in government laboratories.

Regulatory Policies

The one area related to mining for which EMR has a regulatory function is explosives, through the administration of the Canada Explosives Act. In other areas such as mine health and safety or pollution control in mines and mineral processing, EMR advises and cooperates with the federal and provincial regulatory agencies.

It is important that R and D be performed to assist industry in developing operations or processes that will meet current or proposed regulatory standards more efficiently. In EMR's view, closing a plant or mine or reducing productivity as a way of increasing safety or reducing pollution is an admission of failure - although on occasion failures may have to be admitted. Nevertheless the preferred solution is to develop highly productive, safe, and clean mining and mineral processing.

While regulations are generally considered less satisfactory than incentives, they are essential for the orderly development of the Canadian mining and metallurgical industries. They undoubtedly have affected and will continue to influence the R and D of the mineral industry. Using regulations as a technique to enhance productivity is generally resisted by industry, which usually sees the two concepts as opposed. Smelter developments suggest, however, that this need not necessarily be the case.

Fiscal Policies

In supporting, fostering or promoting R and D, the government has two fiscal options: tax incentives and grants.

Tax incentives

These have been revised during 1983, so that industry basically receives a 20-percent federal tax credit for R and D, up from its previous 10 percent. The former 50 percent on incremental R and D over the floating 3-year average has been abandoned. In addition, there is the opportunity to pass on R and D tax credits from the company to investors (Scientific Research Tax Credits); this provides financing flexibility, particularly where a company has no profits against which to write off R and D.

There are still some major problems, however. One is the definition of R and D, which is fairly clear for laboratory work but becomes much more difficult when applied to operations in a producing mine, especially where a company would like to use experimental equipment or new techniques as part of ongoing operations.

Another dilemma is the relationship between R and D and exploration. Both are risky ventures and, if one assumes that the risks are about equal, then it can be argued that the incentives should be similar. Generally, however, exploration is more advantageous, although details depend very much on provincial rather than federal tax structures. The third question is the extent to which work in the development-demonstration-innovation area can continue to be classed as R and D. Again it is mixed up with production. Unfortunately, at this time there is little to offer in the way of answers to these questions, which need a great deal of discussion between the groups involved. The issue in mining is whether the R and D tax laws can be applied to encourage innovative risk taking in a manner which is fair to the industry, and not an unacceptable tax loophole for the government.

Grants

The second general means of fiscal support is through grants such as the IRDP and IRAP programs. The IRDP program is a comprehensive program giving great support to most elements of the technology-productivity cycle. IRAP provides salary support for researchers in industry.

PILP (Program for Industry-Laboratory Projects), administered by NRC, is designed to support technology transfer between government laboratories and industry. Consideration is being given to including universities.

Unfortunately, IRDP is a program directed primarily towards manufacturing; mining (but not smelting and further processing) is excluded. It should be noted, however, that the metallurgical industries and activities related to new materials are eligible for support by DRIE through the IRDP mechanism.

Direct Investment

Because of the influence of government policies and responsibilities, it is inevitable that governments will have views on how the industry as a whole should develop. These views can be reinforced by direct governmental investment through jointly funded initiatives or through the operation of government mission-oriented laboratories.

Joint Initiatives

What kinds of joint initiatives are possible? It is instructive to consider here initiatives generated by both industry and government designed to enhance efficiency and productivity. Three examples will illustrate the spectrum of possible government involvement.

1 Joint ventures such as AOSTRA. This particular example is an Alberta Crown coporation which funds and conducts a wide variety of research, development and demonstration related to the oil sands. Programs include mining, in-situ extraction, processing and refining. Operating companies and other organizations may buy shares in various projects but the results are vested in AOSTRA and are available only to members. The federal government is a participant in some of the ventures through EMR. Intellectual property and technical results are closely controlled.

   There are several features of AOSTRA that would likely render difficult such a development to the mining industry as a whole. It is concerned with a single resource, mainly in one province which controls land leases for development. The sponsoring government expects to gain substantial royalty revenues from oil sands developments; federal policies of self-sufficiency for crude oil ensure a market for the resource; and the operators and landholders in general constitute a small number of major oil companies only. There are no junior mines in the oil sands!

ii The Pulp and Paper Research Insitute of Canada was founded with federal funding for the plant, but operates through contributions from the industry and contracts with specific firms. It is a non-profit corporation whose R and D complements that of the individual pulp and paper companies. It is analagous in many ways to the U.K. and French industrial research institutes. Again, what analogy can be drawn with the mineral industry? PPRI serves an industry more narrowly specialized than the mining industry, without wide variations in processes and with long-term renewable resources. This has apparently enabled the industry to provide a very long-term commitment of support which is essential for the operation of such an institute. The wider variety of minerals, size of firms, regional differences in mining operations, etc. may make this type of arrangement unsuitable. Certainly there is no evidence from government discussions with many different mineral companies that suggests that such a broad institute would be widely and firmly supported by industry. Perhaps in the case of mining, it may be necessary to look at the commodity level for viability.

iii Such an example is the Canadian Carbonization Research Association which provides funds from company memberships for R and D on programs of general interest to coke users, producers and coal suppliers. This again, however, covers a more specialized commodity than mining.

The wide variation in products, size, and distribution of companies and the strong element of competitiveness in the mining industry would likely make any general institute viable only in the long term. Extreme variations of opinion have been encountered in investigating the possibilities of creating a potash institute to be operated by industry after a period of front-end governmental financial support. Perhaps when the present situation is more stable and predictable, and a number of commodity initiatives have been developed further, an overall concept would be worth serious consideration. But should the metal mining industry join with the Coal Association, and for both what should be done about 'further processing'?

Government Laboratories

Prior to the recent difficult economic times, R and D in the mining and mineral industry fitted government policy concepts of how industrial R and D should be performed in the mining, minerals and metals fields, namely that most of it should be done in industry. Our estimate is that in 1980 industry funded about 66 percent ($145M) and government about 21 percent ($47M). It should be pointed out that this performance is more industrially oriented than the national average for R and D suggested by MOSST, where overall industry should fund about 50 percent. Recently the situation in the mineral industry has deteriorated greatly.

In this mosaic, the federal laboratory carries out R and D in-house, and by contract with industry in the mission fields identified earlier. The situation in 1982/82 was as follows. A total of approximately $7.2 million was spent by CANMET on mining technology including coal, with about $2.6 million devoted directly to short- to long-term productivity technologies, mainly on rock mechanics in such areas as pillar stability, roof monitoring, backfill techniques, bulk mining (blasthole stoping) methods and long-range ground stresses. In addition, some of the protection technology research such as reduction of noise and diesel emissions and dust monitoring is also relevant to improving efficiency (e.g. reduced diesel emissions would lower ventilation costs). The Canadian Explosives Research Laboratory also conducts work of relevance to mining, in determining properties of new explosives.

Mining R and D has been identified by CANMET as an area for growth and this has been endorsed by the National Advisory Committee on Mining and Metallurgical Research (NACMMR), an important mechanism to provide industry inputs into government programs.

Current Initiatives

The START Program

Short Term Assistance in Research and Technology (START) started in 1983 is an attempt to focus some of CANMET's expertise and facilities on the immediate problems of industry. START is a 2-year $5-million program, covering minerals and metals but also including areas relevant to mining:

i providing contract funds for industrial R and D in areas such as potash mining and ground stability;
ii inviting industry to place staff temporarily in CANMET to work with CANMET staff on industrial R and D problems;
iii reducing the charges for CANMET investigations of short-term R and D problems of industry where CANMET has special or national facilities and expertise and where it will not cause unfair competition with other research establishments or consultants serving the industry;
iv providing funding for technology transfer.

The program has placed emphasis on determining industry's current site-specific problems and using CANMET to assist in their solutions without cutting off consultants. The 2-year program officially ends in March 1985 but the government will be keeping this situation under review.

As a point of interest, in that part of the program which is contracted out, the government has agreed to some relaxation in the intellectual property rule (1036) for DSS contracts and more general relaxations are under consideration. Such relaxation should assist generally in encouraging joint government industry initiatives in other areas of company-specific R and D.

Beyond START, further short and medium-term developments may be funded using the mechanism of Federal Provincial Mineral Development Agreements where an Economic and Regional Development Agreement has been negotiated between the federal and provincial government, and both governments identify the mineral sector as an economic priority. For example, the Canada-Manitoba agreement, recently initialled, provides $1.6 million in federal and $1.1 million in provincial contributions over 5 years for a series of mining projects including: improved mining techniques to reduce roof instabilities and improve scaling methods; improved communications for isolated areas in mines; CAD systems for underground mines; development of a miners' health hazard exposure index. In addition, there will be projects on tailings control. These projects will be conducted by the federal and Manitoba governments as appropriate, according to a final sub-agreement, together with the Manitoba mining industry. Each government will fund those program elements it delivers and where possible work will be done in mines under contract.

As further opportunities of this kind develop with other regions, EMR will develop with the industry other projects aimed at improving productivity and safety.

Industry is being consulted in different regions to seek their views as to the most effective projects which might be supported with governmental funding and industry cooperation, under such federal-provincial agreements where these are acceptable, or from the current A-Base, or by any other initiative which might allocate the resources. A new generation of Mineral Development agreements which go beyond the traditional geoscientific programs of the past and encompass mining and mineral initiatives with company cooperation appears to be one of the most attractive routes to assist the mining industry. The process levers funding from other levels of government, and many EMR activities will be performed jointly with industry. Indeed it is expected that industry will also directly support the initiatives jointly identified.

Future Thrusts

It is important to consider how future generic initiatives, often with a longer time horizon, can be developed. The CANMET pit slope project was an example of a successful joint project, where federal funds were provided specifically for that project. A recent cost-benefit study concluded that the return on the $15-million project was about $60 million; the project may therefore be considered successful. The technology transfer study has shown also that greater use can be made of a project if its application is more widely understood, and if some aspects are updated in the light of new knowledge.

This and other CANMET technology transfer histories have shown the benefits of focusing limited resources, after industrial consultation, on other significant problems and building up major focused R and D programs. Possible examples in the mining field that may be gathering momentum towards this approach include:

- computer-assisted design for underground mines, especially software packages that do not require sophisticated computing capability and so have wide application in smaller mines;
- prediction of the behaviour of pillars and backfilled areas, especially in deep mines, to provide a better knowledge of stability and greater effeciency of pillar recovery. As an example, an overall reduction of 5 percent of cement in backfill in a particular mine could save $750 thousand per year;
- automatic monitoring of atmosphere in mines and its use to control ventilation;

- integrated communications and control. Sophisticated communications systems for mines (though not yet integrated with controls) are already available, so one might say that the innovation stage is being reached in this area;
- both federal and provincial governments have expressed interest in the possibility of more mining machinery being produced in Canada, and Ontario has funded a resources machinery centre. CANMET has also begun to study robotization and automation in mining and a recent seminar on this topic drew enthusiastic support. EMR involvement is that of a catalyst in applying robotics to mining, rather than as equipment builders.

It does appear therefore that new directions of concentration are developing and these should be strengthened by greated cooperation with industry, and by using all and any funding mechanisms available for projects by single or groups of companies. The START funds for technology transfer have enabled EMR to consult widely with industry in developing these concept so that they will be useful in and adopted by the market.

The Industry-Government Interface

An important part of the system that has been neglected in the past and still has many shortcomings is the interface between industry and government. The interaction of government R and D with industry depends on the industry's view of R and D and government's view of industrial operations. From the laboratory viewpoint, consultative mechanisms with industry advisory groups have shown that it is easier to interface with a company that has a strong R and D department than with one in which R and D is really process control, or where it does not exist at all.

However, since the aim is to put the results of R and D into operation, success in technology transfer depends on the interface within the company between the R and D and operating divisions, or, where there is no company R and D (or where its own interface is poor), between government staff and company operators. There are numerous examples where these interfaces leave much to be desired.

Moreover, the enthusiasm for transfer of technology cannot rest with R and D nor operating staff alone. It must be backed at the highest levels of management in both sectors, otherwise funding is unlikely to be made available either for R and D or innovation, and management will fail in its duty to optimize productivity.

The development of technology, innovation and productivity improvement are long- as well as short-term matters. It is therefore vital that the interface, which is perhaps stronger now than it has been for some years, should not be allowed to weaken when things improve and the need for cooperation in productivity R and D is not urgent, for it is at this time that the foundations for the next round of productivity increases should be planned. Also, to maintain effective liaison in such times, it is essential that government research not over-emphasize the long term or academic.

During the recent downturn in the economy it has become apparent that, in some parts of industry, technological development and innovation have been slow, and catching up with new competition abroad will be difficult or impossible. For the future therefore, the question must be asked whether Canada can afford to be caught with old technology at any time, and to what extent should efforts be made to upgrade processes on a continuing basis.

Enabling Technologies

In particular, the maximum use of 'horizontal' or 'enabling' sciences and technologies must be considered. Enabling technologies of interest include microelectronics and biotechnology, as well as the scientific discoveries in other disciplines that intersect mining. New technologies in such areas arise independent of the mining industry, which is often slow in moving to adapt and use them for the special needs of mining. There is a special problem for R and D in mining, in that the medium in a mine is always changing, and therefore the surface pilot plant concept is rarely applicable. Nevertheless, it will be necessary to make adaptations to mining.

In helping to develop these long-range concepts, government research can play an important and effective role only if the appropriate interfaces with industry are strong. Some government researchers have the essential luxury - if that is what it is - or duty, of being tasked with taking a broad and long-term view of the industry and looking outside for useful developments in other areas. Government laboratories should be able to facilitate the transfer of technology within the industry, facilitate contacts between different organizations with similar interests and assist in the planning of future technological thrusts.

A good example is the government's interest in supporting biotechnology. Thanks to a small group of scientists with very limited A-Base resources, the National Biotechnology Program has agreed to provide some contract funding to CANMET for biotechnology applications in metal leaching and tailings stabilization. BIOMINET, an R and D network of government, industry, university and provincial research organizations for those interested in the applications of biotechnology to mining and mineral processing, is an initial attempt by government to form a continuing liaison in one of the 'horizontal' technologies discussed above.

It is also essential that the attitude of industry concerning confidentiality and proprietary rights be taken into account in establishing R and D networks and long-range programs. Competitiveness can limit the ways in which government can assist. However, from the experience of research associations and EMR contacts with industry, including NACMMR and professional societies, it does appear possible to identify major general problems and longer-range issues that are less subject to the rapidly changing pressures on various parts of the industry.

Conclusions

As a final comment, it is worth re-emphasizing that it is the intent of government that government R and D complement that of industry. The contracting-out policy is directed towards industry at the expense of other organizations (e.g. provincial research organizations), which sometimes causes friction. Government is also endeavouring to support industry in making use of university expertise with a number of imaginative concepts. If all these efforts are to be integrated, good communication will be essential, not only between researchers but with operating staff and right up to senior management.

New industry/government technology initiatives are being developed. Commodity based initiatives may provide a partial answer for some minerals, but in other cases a different approach such as Mineral Development Agreements is required. Government initiatives on a company-government short-term basis have been undertaken under START and will be further developed as described above. For the long term, focused initiatives of a generic nature which sometimes introduce new enabling techologies are being worked out in a variety of dialogues with industry.

The government is committed to working cooperatively with industry, on both short-term R and D issues using the mechanisms described above and on longer-term technology issues in an manner which should focus on the needs of industry. Senior management in both industry and government must be committed to this process if we are going to compete internationally.

Finally, new material developments will need to be very carefully monitored for their potential influence on the minerals industry. But this would be the subject of an even more speculative paper.

EMPLOYEE INVOLVEMENT, PRODUCTIVITY AND COST MANAGEMENT

(or: Wooing the Workforce - what have we learned?)

Peter R. Richardson

Labour productivity is crucial to the competitiveness of the Canadian mining industry. At some underground mines, labour accounts for over 50 percent of operating costs. In addition, operators have the ability to determine the efficiency of capital utilization in most operations.

Many companies now view improved employee relations as extremely important in their efforts to improve productivity and lower costs. A wide variety of initiatives have been undertaken in North America in recent years to accomplish this objective. These range from workplace programs such as quality-of-work-life, quality circles, and job enrichment, through productivity improvement schemes, including the Scanlon plan and gain-sharing, to corporate profit sharing programs, such as Improshare.

The Canadian mining industry, in its typically conservative approach to human resource management, has not rushed headlong to embrace these approaches. Nevertheless, in recent years a number of different initiatives have been undertaken by a variety of firms. The purpose of this paper is to describe some of these, analyze their common characteristics and discuss their results. Non-union operations will be discussed briefly, but the majority of the paper will focus on employee-centred initiatives in unionized operations.

Non-Union Operations

A few firms in the Canadian mining industry have managed to establish a partnership with their workforces that precludes the necessity for a union. Two of these companies are Kidd Creek Mines, which inherited the Texasgulf employee relations philosophy, and Selco Limited. Both these companies possess high quality orebodies which have provided the profit margins necessary to underpin their employee relations policies.

These firms have made outstanding efforts to involve all employees as partners in the business. Their approaches are characterized by a high degree of top management commitment and involvement in employee relations activities, extensive and pervasive communications, all employees on salary, and a tangible commitment to the welfare of each individual in the workforce. This commitment requires an extremely large amount of management time to be spent on building and maintaining trust and cooperation. However, executives in these firms maintain that the costs are more than justified by the operational flexibility inherent in the approach, and the resulting performance.

Since these firms are atypical of the majority of firms in the industry, their employee relations policies will not be described in further detail in this paper. The Kidd Creek approach was discussed at length in a paper prepared for the fourth CRS Policy Discussion Seminar on Employee Relations Initiatives in the Canadian Mining Industry (Cawsey and Richardson: 1979). At that time our major concerns about the future of their program were possible management complacency leading to degradation of the program, and a perception on our part that management did not organize sufficiently to maximize individual contributions to productivity improvement and cost reduction.

Initiatives in Unionized Operations

Most Canadian mining operations are unionized, and their employee relations have traditionally been characterized to a greater or lesser degree by mistrust and confrontation, rather than trust and cooperation.

In recent years, a number of companies have attempted to improve employee relations through a variety of initiatives. These have taken a variety of forms, reflected in the diversity of approaches adopted by four separate operations whose initiatives form the basis for the remainder of this paper:

i an operation-wide quality of work-life program in which productivity was a hoped-for by-product;

ii an operation-wide employee effectiveness program through increased participation.

iii a cost reduction program through employee involvement without tangible financial rewards to employees;

iv A cost reduction program employing a gain-sharing reward structure.

Table 1 provides further detail on each of these companies and their approaches.

In all four instances, patterns and themes reappear which suggest that there are a number of common pitfalls that await all firms who attempt this road. In addition, there is a distinct life-cycle through which all participative management programs appear to pass. Mining managers who are developing, or are in the process of implementing, such approaches should be aware of these factors.

The initial reaction of unions to these initiatives is usually hostile. Very often they are perceived as attempts by management to buy off the workforce or reduce the power of the union. As one shop steward commented:

> Management usually introduced these programs when times are tough, and they want to share the bad news. However, once business picks up, they don't want to know any more.

Once employees have been through a couple of these experiences, they treat new programs with due cynicism and scepticism.

For this reason, executives are realizing that there had better be a commitment to maintaining these programs throughout the business cycle if they are to result in continued productivity improvement. In addition, they have found that:

- participative management is not an end in itself;
- participation should be tied directly to improved safety, productivity and lowered costs;
- building participation is a time-consuming process;
- participative management should not be placed on a pedestal.

Participative Management is not an End in Itself

There is no evidence to suggest that, by itself, participative management produces organizational performance that is superior to traditional directive or autocratic styles. Indeed, in an operation where the production task is well defined, and management, supervision and workers are comfortable with a directive approach, the costs of introducing a participative style may outweight the benefits.

The introduction of any new style of management to an organization creates an hiatus. Attitudes are unfrozen,

Table 1

CHARACTERISTICS OF THE FOUR COMPANIES AND THEIR PROGRAMS

	Company 1	Company 2	Company 3	Company 4
Type of Operation	Integrated base metal producer	Copper smelter	Base metal mine	Base metal mine
Employees:				
Staff	800	220	110	420
Hourly	1900	770	500	1280
Payroll as percent of total cost	55	47	32	51
Unions:				
Staff	Yes	No	No	No
Hourly	Yes	Yes	Yes	Yes
Type of program	Employee effectiveness through participation	Cost reduction Employee involvement	Quality of work life	Cost reduction Gain sharing
Year initiated	1977	1981	1977	1978
Status in 1983	Dormant	Management supervisory honeymoon Significant tangible cost reductions Voluntary hourly involvement	Improved morale and attitude No tangible cost or productivity gains	In crisis after major successes Lost top management support Operating management complacent

tasks are redefined and, in the transition, performance may suffer. If the new style is not adopted throughout the organization, it is likely that new norms will not be accepted and supervisors and workers will be confused (and de-motivated) by apparently conflicting forms of decision making. All four companies studied experienced a period lasting up to 24 months during which there was constant questioning of management motives, organizational processes and decision-making procedures.

Participative management generally requires changed attitudes as well as a lot of work from the entire management team. Before it is adopted, companies should make sure there are benefits to be gained, and the the entire top management group is committed to making the approach successful. Senior executives from a remote head office whose decisions may affect the outcome of the program in a particular plant should be included in this group.

Take all the Time That is Necessary

Changing management styles is a time-consuming process, the stages of which are detailed later in this paper. Proceeding too rapidly exposes the organization to a number of risks which could lead to the failure of the initiatives.

Once the senior management group has sold itself on the idea, it is dangerous to assume everyone else will want to go along. The companies in this study found that it took at least one or two years just to bring all levels of supervision fully into the process. Supervisors accustomed to a directive style of management find it hard to discuss issues openly with their managers, and are often uncomfortable seeking out employee views on decisions that they would formerly have taken unilaterally. Going too fast in an attempt to involve hourly-paid workers may leave supervisors feeling isolated and uninvolved.

Workforce involvement on a formal basis, through productivity bonuses or profit-sharing, should only be initiated when several conditions have been met. Supervisors must be trained and capable of handling the new style of supervision. A reasonable period of operating stability should be available in which to implement the change (not just before layoffs or negotiations!) and a core of worker support must have been created.

Tie in Participation to Improved Productivity and Lower Costs

A number of programs of this type have started out with increased participation as the main objective and, through that, improved organization effectiveness. The evidence on this approach suggests that the outcome may be improved employee attitudes and morale, but little overall increase in organization performance. In the long run, senior executives will question and evaluate the supposed benefits of this type of activity. Their support may be lost if tangible results are not evident.

A large Canadian mining company instituted a participative approach in 1977 in its mining operations and, since then, throughout the entire company. The direct cost of the program has been in excess of $2 million. The firm's market and financial performance during that period has been significantly and tangibly worse than its competitors. Operating managers became overly concerned with being participative, and failed to take hard decisions. Layoffs initiated by senior executives in the head office have shaken the confidence of employees in the program. Participation does not mean abdication.

By way of contrast, two of the operations studied developed comprehensive cost management programs in which employee involvement has a major role to play. Supervisors did not lose sight of the fact that the overall goal was more effective operation in terms of unit costs. At the same time, however, involvement was encouraged through joint discussion and action on problems and opportunities in the work place.

Don't Make a Major Production out of the Activity

'Today is the first day of the rest of our lives' would not be an appropriate way to introduce a participative management activity. A number of participative schemes, such as Quality of Work Life and Quality Circles, are meeting resistance from labour as soon as management announces them. Announcing programs in this manner at the start provides a focus for informal activities by troublemakers which can undermine moves towards participation.

In each of the plants studied, between 10 and 20 percent of the workforce greeted the new approach with enthusiasm, joining in decisions and activities voluntarily. Approximately 70 percent were largely indifferent, and 10 percent were openly critical or hostile. In all four cases studied, management had to continually evaluate decisions and proposed actions to ensure that they could not be misinterpreted by the disaffected group.

In addition, by announcing the program formally, supervisory and workforce expectations may be created which cannot be met in the short term. This is not to say, however, that once the activity is underway and has momentum, some high-profile joint activities cannot be introduced. Such activities can build on and reinforce a climate of co-operation once it has been created.

The Life Cycle

Participative management is like wooing a wife - the heady days of romance are soon replaced by the reality of making the marriage work. On the way, you have to make sure that supervision, like the mother-in-law, approves. Otherwise they can make your life hell!

The steps in the evolution of each of the programs described here was as follows:

- becoming interested;
- wooing supervision and the workforce;
- consumating the union;
- a romantic interlude;
- complacency;
- renewal; or,
- failure.

Becoming Interested

The impetus for change in management style, and the accepted approach to operating, must stem from the managers of specific plants identifying specific value to their operation. Head office cannot mandate these activities since the essential commitment of operating managers is likely to be lacking. One company in this study adopted a participative approach as a company philosophy but was unable to carry it through within operations where managers thought it inappropriate. However, as a major investment in management and supervisory time is to be made, tangible returns should be expected by the corporation.

The best situation, the companies in this sample have found, is where greater involvement of workers and supervision in problem solving and decision making can result in measurably lowered unit costs. Identifying costs as a common target is something all employees can identify with. Productivity suffers from 'sweat-shop' connotations among workers, while participative management by itself offers little of value to management and supervisors.

The contribution of this activity to the total cost management effort of one operation studied here looked as follows over a five-year period:

Contribution of new capital investment -	16%
Contribution of new technology -	8%
Workforce contribution -	8%
Total reduction in real terms as a percentage of current cost -	32%

Other operations studied chose initially to stress non-economic benefits:

- improved cooperation;
- better work environment;
- less management time fighting fires;
- lower rate of grievances;
- improved safety records.

While these effects are desirable, experience has shown that these indicators may not be translated into measurable cost and productivity gains.

Once benefits have been identified, the senior management group must agree to support such an activity. There is no doubt that many managers feel threatened by 'participation'. Others are skeptical of the supposed benefits. However, for the activity to have a chance to succeed, the whole management group must be prepared to 'give it a go'. There is considerable merit in a full and frank discussion of each manager's views prior to a decision to proceed. One operation had its whole effort undermined by the lack of a tangible support from one senior departmental manager.

Faced with such a situation, it may be tempting for the vice-president or general manager of an operation to commence a demonstration project in one department. The evidence from this sample of firms suggests this approach will not be successful. A participative sub-culture within an autocratic overall culture has little chance of long-run survival. Two companies experienced the rapid demise of Quality of Work Life schemes initiated in single departments of larger plants.

Moreover, participative management probably already exists to some extent in any department where managers are so inclined. The commitment of the whole organization provides an umbrella.

Wooing the Workforce

The experience of companies in this sample suggest that negative views on greater worker involvement can usually be expected from the union and about 10 percent of the workforce. These groups will be looking for any actions that suggest management is using the activity to manipulate the workforce. On the other hand, there will be between 10-20 percent of the workforce who welcome the opportunity to participate more extensively. The majority will initially be indifferent.

Wooing the workforce involves demonstrating that there are mutual management-labour benefits from greater involvement. Extreme care must be taken to avoid actions which can provide detractors with an opportunity to permanently taint the program. In addition, management must gain involvement through the implementation of appropriate management actions (consultation, equity, openness) and not by preaching the doctrine.

At this point, management gains cooperation by:

- demonstrating a willingness to communicate about the operation (information sessions on competitiveness, financial results, and major changes) and inviting questions and comments;
- encouraging supervisors to hold regular crew meetings (training in holding effective meetings is advisable);
- providing enthusiastic employees with opportunities to participate in problem-solving activities (suggestion schemes, cost reduction projects, participation in capital projects);
- rewarding and/or promoting supervisors who demonstrate appropriate leadership styles and instituting remedial action where styles are inappropriate.

No attempt should be made to force employee involvement. Rather, management should seek and encourage greater involvement and reinforce success by rewarding and publicising notable employee contributions.

Consummating the Union

There arrives a point at which management feels that there is a ground swell of support for a participative management approach among the workforce. At this point, the decision has to be made to institutionalize and formalize the relationship. At this time a number of actions can be undertaken:

- management can clarify the areas in which greater involvement is being sought (safety, problem solving, productivity increase, cost reduction, general decisions affecting the operation);
- union/worker representation on a variety of operating committees can be sought;
- specific, high-profile, worker-involvement activities can be initiated;
- rewards can be offered for worker involvement resulting in improved operations.

As an example, at this stage in the process, one operation:

- issued a plant-wide statement of management philosophy;
- 'opened the books' to the union;
- sought union/worker representation on crew committees in each work place, as well as safety and cost-reduction committees for the whole operation;
- initiated an annual six-week participative cost-reduction program, with small rewards for all involved employees;
- toughened up on well-known abuses of work practices (by approaching the workforce);
- implemented a program of brightening up the general work environment.

There are a wide variety of mechanisms to gain greater involvement and the above list is by no means exhaustive. Each operation has to tailor its agenda to its own specific situation. Timing is important, however, and caution should be exercised in deciding when to make this move. For instance, it is not advisable to take the step in the period leading up to contract negotiations.

A Romantic Interlude

Carefully implemented, the above approach results in a 'honeymoon' period for management and the workforce. During this period a variety of social indicators improve:

- workers express more interest and take more care;
- fewer grievances arise;
- jobs-jurisdiction disputes decline;
- managers and supervisors spend less time fighting fires.

In addition, if the activity is properly structured, a natural productivity increase occurs, accompanied by lower costs due to:

- reduced maintenance;
- greater efforts to maintain production;
- a pent-up supply of suggestions to improve productivity.

However, to maintain these one-time gains, a continuing emphasis on productivity and costs is necessary.

Complacency

Somewhere between a year and two years into the program, the honeymoon ends. Management and supervision start to take the activity for granted. Change has been accomplished and everyone relaxes. At the same time, though, there remains suspicion among certain radical elements of the workforce.

At this point, there can be considerable danger to the entire activity from the following types of events:

- management and/or supervision ceases to communicate and listen;
- management unilaterally takes decisions which are viewed by supervisors and/or the workforce as part of the participative agenda;
- management fails to address issues of major concern to the workforce;
- everyone becomes concerned with employee feelings and behavioral issues, resulting in a decision paralysis.

The operations covered in this paper have experienced all these problems. At one operation, crew meetings ceased after about a year. At another, layoffs led to a breakdown in trust. At a third, concern for 'participation' led to poor operating decisions when markets turned down and hard decisions were needed.

At this stage, it only takes one or two such instances for workforce skeptics to become vociferous and for trust in management and the activity to decline precipitately. External factors can also affect the activity. For instance, changes in business conditions can lead to circumstances in which management feels less willing or able to involve the workforce. (The need is most keenly felt when margins are slim and all avenues to reduce losses/increase profits are being sought.) Changes in management and policies in the corporate office can also affect these activities.

Renewal ... or Failure?

Overcoming this period of complacency requires a renewal of the activity. This process requires senior management to reinforce the values and philosophy embodied in the program by demonstrated actions and decisions. These include identification and resolution of outstanding supervisory and workforce issues concerning continuing employee involvement.

In addition, routine activities such as crew meetings and problem-solving activities have to be encouraged. New ideas and programs to promote workforce involvement have to be developed. At this stage (4-5 years after the initiation of the activity), some form of gain-sharing program might be considered.

Lack of recognition of this period can lead to growing skepticism of management's intentions by supervisors and the workforce which can lead to the ultimate breakdown of employee involvement. Once this has occurred, past experience suggests that it is almost impossible to revitalize the activity without extensive changes to the management structure.

Concluding Comment

The experiences of the Canadian mining companies which form the basis for this paper demonstrate that productivity improvement through employee involvement is a viable but tough strategy to implement. The returns can be substantial in both economic and personal value for the operation and its employees. However, the initiative involves substantial risk, and may end up as a failure.

The single most important factor affecting the success of the programs described here was the commitment of top management to the approach, and their involvement in its implementation. Not only was this necessary for a successful start-up, but top management interest has a direct influence on the continuity of the approach. Maintenance cannot be delegated to lower level managers and supervisors.

For some, the most surprising finding of the study will be the extent to which union, workforce and management can agree, and work together on what appear to be tough cost and productivity objectives. The fact is that unions and employees understand economic reality, and are willing to accept fewer jobs, as long a they are secure, and as long as necessary terminations allow employees to leave with dignity and a viable economic future. Those who remain can then have pride in their contributions to the competitiveness of their operation. All it takes, it appears, is good no-frills management, and a willingness to communicate and cooperate.

APPENDIX I LIST OF SEMINAR PARTICIPANTS

John L. Bonus
Managing Director
Mining Association of Canada
Ottawa, Ontario

Denis R. Bridger
Vice President, Operations
Selco Inc.
Toronto, Ontario

Beverley Brooks
Department of Finance
Ottawa, Ontario

J.H. Brown
Mining Engineering
Queen's University
Kingston, Ontario

Walter Curlook
Executive Vice President
Inco Limited
Toronto, Ontario

Michael Daly
Senior Economist
Economic Council of Canada
Ottawa, Ontario

Dallas Davis
Mining Consultant
Fredericton, N.B.

Brian Felske
Brian E. Felske & Associates
Toronto, Ontario

Jim E. Finlay
Executive Coordinator
Mineral Resources Division
Min. of Natural Resources
Toronto, Ontario

Gaston Gendreau
Gen. Supt. - Transport
Quebec Cartier Mining
Port Cartier, Quebec

George S. Hamilton
Partner
Woods Gordon
Toronto, Ontario

John Henderson
Mineral Policy Sector
EMR
Ottawa, Ontario

William James
President and C.E.O.
Falconbridge Limited
Toronto, Ontario

J. Trevor Jubb
Deputy Director-General
CANMET
Ottawa, Ontario

Eric Kossatz
Vice President, Mining
Ontario Division
Inco Limited
Copper Cliff, Ontario

Paul LePage
Sub-District Director
Maritimes, USWA
Bathurst, N.B.

Donald C. Lowe
President and C.E.O.
Kidd Creek Mines Ltd.
Toronto, Ontario

Brian W. Mackenzie
Interim Executive Director
CRS
Kingston, Ontario

Henry L. Martin
Resource Policy Division
Mineral Policy Sector
EMR
Ottawa, Ontario

C. George Miller
Assistant Deputy Minister
Mineral Policy
EMR
Ottawa, Ontario

Jacques Nantel
Mining Engineering
Queen's University
Kingston, Ontario

J. Andre Potworowski
Office of Technol. Transfer
CANMET
Ottawa, Ontario

Philip L. Reeves
Mineral Policy Advisor
Geology and Mines Division
Energy and Mines
Regina, Saskatchewan

Peter R. Richardson
School of Business
Queen's University
Kingston, Ontario

Kenneth R. Stollery
Department of Economics
University of Waterloo
Waterloo, Ontario

Ken Whitham
Res. and Technol. Sector
EMR
Ottawa, Ontario

Margot J. Wojciechowski
Assistant Director
CRS
Kingston, Ontario

Roy M. Woodbridge
Director, Mineral Economics
Mining Assoc. of Canada
Ottawa, Ontario

APPENDIX II PROGRAM:

13TH CRS POLICY DISCUSSION SEMINAR ON MINING PRODUCTIVITY

Wednesday March 7, 1984

7:00 p.m. **Canadian Mining Productivity and Competitive Position in International Markets**
Brian Felske, Brian Felske Associates

Thursday March 8

9:00 a.m. PRODUCTIVITY MEASUREMENT

The Economic Perspective:
Productivity Trends in the Canadian Mining Industry, 1957-79
Kenneth Stollery, Dept. of Economics, University of Waterloo

The Geological Perspective:
Economic Productivity of Canada's Base Metal Endowment: Is the Quality Declining?
Brian W. Mackenzie, Centre for Resource Studies

1:00 p.m. THE CORPORATE AND GOVERNMENT POLICY ENVIRONMENT

Government Initiatives Relating to Productivity Incentives
C. George Miller, Mineral Policy Sector, EMR

Industry Needs for Productivity Improvement
William James, Falconbridge Ltd.

Labour Perspective on Public and Private Sector Policies Needed for Productivity Improvement
Paul LePage, United Steelworkers of America

7:00 p.m. Discussions

Friday March 9

9:00 a.m. PRODUCTIVITY IMPROVEMENT INITIATIVES

Inco's Research Mine
Walter Curlook and Eric Kossatz, Inco Limited

Possible Industry/Government Technological Initiatives
Kenneth Whitham, Research and Technology Sector, EMR

Employee-Centred Productivity Initiatives
Peter R. Richardson, School of Business, Queen's

1:00 p.m. Discussions

3:00 p.m. Conclusions and Recommendations

THE AUTHORS

Walter Curlook graduated from the University of Toronto, where he received a B.Sc. and a Ph.D. in metallurgy. He joined Inco in 1954 as a research metallurgist, and in 1974 was named Vice President of Inco Ltd., in charge of corporate planning. He has since served as Senior Vice President of Inco, and President and Chief Executive Officer of Inco Metals. Dr. Curlook's present position is Executive Vice President of Inco Limited. He has also held many positions in the mining industry organization, including that of President of both the Ontario Mining Association and the Mining Association of Canada.

William James is a graduate of the University of Toronto, with a B.A. and M.A. in geology. He also holds a Ph.D. from McGill University. Dr. James worked in a variety of mining and consulting firms as a geologist and consultant, and in 1973 joined Noranda Mines. In 1974 he was named Executive Vice President of Noranda. In 1982 he was named President and Chief Operating Officer of Falconbridge Limited, and the following year became Chairman of the Board and Chief Executive Officer. In 1984 he was also elected President of the Mining Association of Canada.

Eric Kossatz graduated from the University of Toronto with a B.Sc. in Mining Engineering. He joined Inco in 1953, and over the years has been manager of the Shebandowan, Levack, and Frood-Stobie mines. Mr. Kossatz is now Vice President, Mining, Ontario Division of Inco Limited.

Paul LePage is sub-district director, United Steelworkers of America, for the Atlantic provinces. He was president of the New Brunswick Federation of Labour for 13 years, and regional vice president of the Canadian Labour Congress for 12 years. Dr. LePage has also served on the Atlantic Provinces Economic Council, the New Brunswick Labour Relations Board, and as a delegate to the Law of the Sea Conference. In 1978 he received an honorary doctorate in law from St. Francis Xavier University.

Brian W. Mackenzie, a native of Winnipeg, was born in 1939. He holds a B.Eng. (Hon.) in mining from McGill University, an M.Sc. in mineral economics from the University of the Witwatersrand, and a doctorate in engineering science (mineral economics) from Columbia University. After working as an engineer in mines in Canada and South Africa, he became an assistant inspector of mining leases for the South African government, and later worked as a mineral economist with Energy, Mines and Resources in Ottawa. Dr. Mackenzie then taught in the Department of Mining and Metallurgical Engineering at McGill University, where he was director of the mining program, until 1977. In January 1978 he became a research associate of the Centre for Resource Studies and a professor in the Department of Geological Sciences at Queen's University, and for periods from 1981 to 1984 served as Interim Executive Director of CRS. In 1979 Dr. Mackenzie was named distinguished lecturer in mineral economics by the Canadian Institute of Mining and Metallurgy, and in 1983 he received their 'Robert Elver Mineral Economics Award'. He has presented mineral economics seminars in Canada, Australia, Brazil, Chile, South Africa, Tanzania, Indonesia, China, and the United States.

Henry Martin graduated from Queen's University with a B.A. in geology, and worked as a geologist with the petroleum industry and the Geological Survey of Canada. In 1971 he joined the Mineral Policy Sector of Energy, Mines and Resources, where he is now Senior Mineral Economist in the Resource Policy Division.

C. **George Miller** was born in Winnipeg in 1932. He holds degrees in Engineering and Chemistry from Queen's University and Oxford University. Following a post-doctoral fellowship at the National Research Council, he spent two years in a tobacco research laboratory. In 1960 Dr. Miller joined Celanese Canada Limited, where he held a number of technical and management posts including managing director of Chemcell S.A. (Switzerland) and general manager, chemicals. In 1972, he became vice-president of Stanley Associates Engineering Limited, Edmonton. He was appointed executive director of the Centre for Resource Studies in 1974. In 1981 Dr. Miller became Assistant Deputy Minister, Mineral Policy in the federal department of Energy, Mines and Resources, and in 1984 he moved to the Mining Association of Canada, where he is Managing Director. A professional engineer, Dr. Miller is also a member of the Canadian Institute of Mining and Metallurgy and a Fellow of the Chemical Institute of Canada.

Peter R. Richardson was born in Sheffield, England in 1947. He holds the degrees of B.Sc. (Honours) from Leeds University and a Ph.D. in Business Administration from the University of Western Ontario. Following a teaching appointment at the Iran Center for Management Studies in Tehran, he joined the faculty of the School of Business at Queen's University in 1977. He has served as consultant and provided management training courses for a number of corporations in the mineral industry. Dr. Richardson is a faculty associate of the Centre for Resource Studies and an associate professor in the School of Business.

Kenneth R. Stollery has a B.A. in Economics from the University of Southern California, and the degrees of M.A. and Ph.D. in Economics from Queen's University. Dr. Stollery's research interests include environmental controls in the mineral industry, mineral industry productivity, mathematical models of fisheries exploitation, and effects of taxation on mineral investment. He is Assistant Professor at the University of Waterloo, where he has taught economics since 1974.

Kenneth Whitham graduated from Cambridge University with a B.A. in natural sciences, and received a Ph.D. in physics from the University of Toronto. He joined the Department of Energy, Mines and Resources where in 1964 he was appointed chief of the Seismology Division, in 1973, director general of the Earth Physics Branch, and in 1980, Assistant Deputy Minister, Research and Technology. In this position, Dr. Whitham is responsible for mineral and energy research in CANMET, and other related programs including the formulation of policy advice on research and technology developments in minerals and energy across Canada.

THE CENTRE FOR RESOURCE STUDIES

The Centre for Resource Studies (CRS) was established in 1973, under the sponsorship of Queen's University, the federal Department of Energy, Mines and Resources, and The Mining Association of Canada, to carry out a program of research and publication on mineral policy issues.

The Centre provides opportunities for multidisciplinary research in resource studies at Canadian universities, furnishes reliable information on matters related to mineral resource policy, and promotes closer liaison between government, industry and other concerned groups. The research program is carried out both at the Centre and by means of contracts with qualified investigators, usually at Canadian universities. Small exploratory studies are also funded, through a system of grants-in-aid of research. CRS Seminars involve representatives from governments, industry, universities, labour, and other interested groups in working sessions on issues of current concern. Through this program of research and seminars, and the resulting publications, the Centre contributes to informed discussions and a better understanding of significant issues.

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Most of the funding for the Centre's activities is provided by two of the sponsors, EMR and MAC. In addition, the Centre accepts contracts from other organizations interested in mineral policy research.

The Centre welcomes comments on its publications, proposals for research projects or for publication, or enquiries about any aspect of its work. For further information, contact:

Centre for Resource Studies
Queen's University
Kingston, Ontario, Canada K7L 3N6
(613) 547-5957

CRS PUBLICATIONS

Monographs and Collections

Conflict and its Resolution in the Administration of Mineral Resources in Canada, by R.M. Burns; 62 pages, 11 tables. Published 1976.

The Impact of the Mining Industries on the Canadian Economy, by R.W. Boadway and J.M. Treddenick; 116 pages, 15 tables. Published 1977.

The Transportation Impact of the Canadian Mining Industry, by A.I. Wallace; 154 pages, 17 tables. Published 1977.

Human Resources in Canadian Mining: A Preliminary Analysis, by J.A. MacMillan, G.S. Gislason, and S. Lyon; 174 pages, 48 tables. Published 1977.

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The Canadian Nonferrous Metals Industry: An Industrial Organization Study, by E. Urquhart; 158 pages, 18 tables. Published 1978.

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Effects of Taxation on Base Metal Mining in Canada, by B.W. Mackenzie and M.L. Bilodeau; 188 pages, 29 tables. Published 1979.

Gold: The World Industry and Canadian Corporate Strategy, by E. Cousineau and P.R. Richardson; 192 pages, 32 tables. Published 1980.

The Impact of Policy Change on Decisions in the Mineral Industry: The Case of Exploration in Manitoba, 1969-77, by B.E. Owen and W.J. Kops; 116 pages, 8 tables. Published 1980.

The Role of Mineral Taxation in Industry/Government Conflict: The Case of the Saskatchewan Potash Reserve Tax, by David L. Anderson; 135 pages, 41 tables, 2 illustrations. Published 1981.

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Eastern Arctic Study

(Published jointly by the Centre for Resource Studies and the Institute of Local Government)

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